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Notes on Stability from the Pilot's Standpoint

MELVIN N. GOUGH

National Advisory Committee for Aeronautics

THE desirability of some form of stability in modern airplanes is recognized. The range between dangerous instability and the generally known undesirable condition of too much stability is so wide as to make it difficult, if not impossible, to say where any present-day conventional airplane fits into the general picture, or even how its relative handling characteristics as judged by the pilot compare with those of another airplane. The existing flight characteristics should be studied on a more quantitative basis to remove the uncertainty as to the essential characteristics, and how they are affected by structural features.

The National Advisory Committee for Aeronautics has started a program to study in detail, by means of instruments measuring airspeed, control disposition, and airplane motion and attitude (all synchronized with time and personal observations), the magnitude of the many variables that go to make up flight characteristics. Tests have already been conducted on six airplanes ranging in size from 4000 to 70,000 pounds and having from one to four motors. Although the quantitative data are not yet available, the exactness and the comparable nature of the test procedures have resulted in additional piloting experience and, it is believed, will allow a more definite expression than has heretofore been possible regarding a few of the known desirable and undesirable stability characteristics of modern airplanes. It is the purpose of this paper to present some notes taken from those experiences and to interpret them from the pilot's viewpoint.

Before specific examples are given, the general features will be discussed. An airplane lacking in stability can be successfully flown if the control is sufficiently delicate and precise that disturbances in attitude due to control movement or to a gust can be immediately corrected. With control and stability both inadequate, the airplane is definitely dangerous. A certain amount of inherent stability is necessary and the amount obviously depends upon the use for which the airplane is intended. A high degree of stability tends to decrease the sensitivity of the controls and the greater the stability, the greater the demands on the pilot and the rougher the flight. There is, however, no indication that the stability of present-day airplanes *should not* be twice as great as it is.

Obviously, a variation in the relationships between stability and control with variation in flight conditions is to be expected. For instance, in the cruising condition, desirable stability relieves the pilot of considerable strain, whereas in the landing operation, which requires his constant attention for a short period, he would prefer that good control features predominate.

It is difficult to draw general conclusions applicable to all airplanes. The relative importance of the many factors that affect stability must differ widely for different planes. The important factors for the safe—probably two-control—airplane for the private owner are entirely different in degree from those required for the airplane intended for the skilled military or combat pilot. Both requirements are at variance with the transport requirements, which consider the safety and comfort of the passengers under skilled guidance. A most desirable condition in the interest of general safety would seem to be one in which an airplane, if left entirely to itself, would always return to its original flight condition, with regard to its lateral and longitudinal attitude, regardless of heading.

The controlled and the natural motions of an airplane along and about its three axes can be partly separated and considered in two independent groups: the longitudinal motions (those in the fore-and-aft vertical plane); and the lateral motions, including sideslip with its resultant rolling and yawing action.

Longitudinal Stability

Longitudinal stability and control probably affect successful flight more than any other characteristics.

Presented at Air Transport Meeting of the Institute, Chicago, Illinois, November 19, 1938.

Since these characteristics have to do with angle of attack, they also have a bearing on the stall, as will be discussed later. It should be possible by means of the elevators to produce equilibrium and to maintain steady flight at any speed in the allowable range, under any power conditions, loading, or position of the landing gear and the flaps. The variation in the control force and the elevator position required to change from one balance speed to another is an indication of the static longitudinal stability. With zero stability, the speed of the airplane may change without any change of control force or position. Even though the elevators are held steady there is no assurance that, owing to an external disturbance, the speed may not decrease and the airplane may not be inadvertently stalled in presumably steady flight.

With logically operated elevators, such as can exist on a statistically stable airplane, the pilot can always determine attitude by the magnitude and the direction of the control forces. A very high degree of stability would, of course, cause large control-force and position variations for trim. Regardless of degree, it should be possible for the pilot, when the airplane is once trimmed for a condition of equilibrium, to check back on his speed by permitting the controls some freedom.

Fig. 1 shows what the author believes to be the desirable variations of elevator control force and position with airspeed. The top curves show that, from any trimmed condition, a pull force is required to decrease the speed and a push force to increase it. Further,

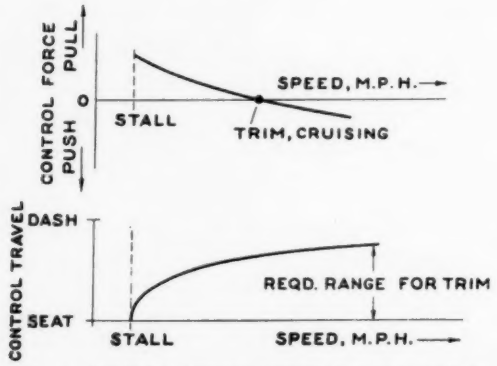

FIG. 1. Desirable elevator control-force and position variations with airspeed.

the magnitude of the pull force increases rapidly as the speed is reduced. The lower curve shows the variation of control position. It will be noted that a definite and increasing displacement is required to change the speed to a lower value; in fact, almost the entire amount available is required to produce the stall. The location of the control in the cockpit is an indication to the pilot of the flight condition existing.

Unfortunately, the degree of static longitudinal stability of low-wing monoplanes is least at low speeds. The low wing therefore has an inherent disadvantage over other arrangements in that very small variations of control force and position with speed will be obtained, particularly in the vicinity of the stall.

In contrast to the ideal static longitudinal stability shown by the control-force and position variations with airspeed in Fig. 1, the typical low-wing monoplane of the present day actually has the control forces and positions shown in Fig. 2. The small force variation

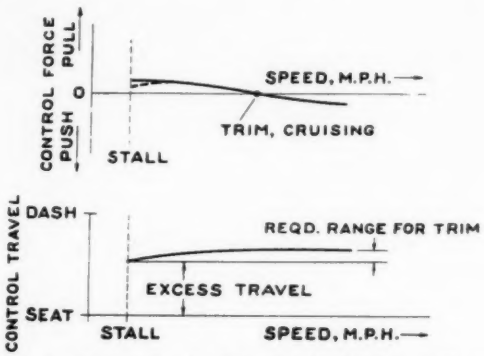

FIG. 2. Present trends of elevator control-force and position variations with airspeed.

with variation in airspeed at low speeds will be particularly noted. In other words, the elevators have no "feel." From the position curve it is noted that the control is well forward when the stall occurs. In fact, the control moves so little through the entire speed range that its possible usefulness as an indication of flight conditions is lost.

These conditions are well substantiated in flight. In the large modern airplane a smaller force may be required on the controls to hold a lower speed than that for which it was originally trimmed. In fact, on one large airplane, trimmed for cruising at 165 m.p.h. with zero force, the force change required to trim throughout the speed range from 165 to 85 m.p.h. was but one pound, and that slight variation was in the opposite direction to that required for stability. Of the available 20 inches of fore-and-aft travel of the control wheel, only 5 inches, and that in the middle of the range, were required to achieve balance *under all conditions*. The addition of power aggravates the case and reduces the stability; various flap and landing-gear positions may have an effect in either direction. Rearward center-of-gravity movement always detracts from stability and the transport airplane, with its necessarily large loading schedule, thereby suffers the most.

Fig. 3 shows the actual control forces required on a large low-wing monoplane to trim at various speeds. In all cases, the center of gravity was considered to be in a normal position. Each of the take-off, cruising, and landing conditions are drawn for three trim-tab positions to show the powerful effect of the tabs and the manner in which they cause the control forces to vary with speed. It is evident from the shape of the

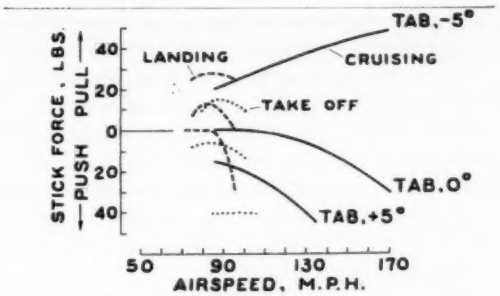

FIG. 3. Representative control-force variations with airspeed for modern low-wing monoplanes.

curves that the pilot has little chance of determining his flight condition by the feel of the controls. Two other points should be mentioned in connection with this figure. First, these curves and those of Fig. 4 do not refer to the worst cases; they are representative of the large airplanes thus far tested. Second, the forces

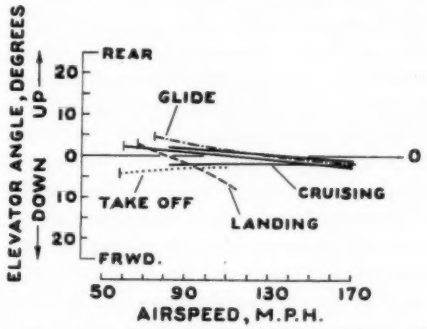

FIG. 4. Representative control-position variations with airspeed for modern low-wing monoplanes.

shown are the ones that must be held constant to maintain trim at a given speed. Changing from one speed to another will require greater forces, the magnitudes of which will depend on the rate at which the controls are moved, bringing into account their inertia, as well as the friction in the system.

Fig. 4 shows the control-position changes occurring in flight with the same airplane for which Fig. 3 was drawn. Elevator angles are shown but they vary linearly and directly with control travel. The cruising condition is shown for the three center-of-gravity positions (forward, normal, and most rearward) to show their effect on stability. Note the unstable slope of the lower curve corresponding to the rearward center-of-gravity position. The change in slope effected by reducing the power in the cruising condition to produce the gliding condition and the further change brought about by lowering the flaps and landing gear to produce the landing condition should be noted. A partial power landing condition is not shown, but it can be visualized by noting the take-off condition with flaps partly down. The very small range of elevator travel required by any one condition and the small total travel used by all conditions is particularly noteworthy. These illustrations indicate the pilot's dependence on the airspeed meter and help disclose a condition of static stability in which improvement is most desirable.

Complete and comparable tests previously made on a number of airplanes showed that dynamic longitudinal stability, as defined by the period and the damping of the oscillations, has no apparent bearing on the factors by which a pilot judges the handling characteristics. The natural oscillation and the damping of the free motion of the airplane do not appear because the pilot accommodates his use of the controls to governing these inherent tendencies. Accordingly, dynamic stability or instability will be apparent only from the movement of the controls required to perform a given maneuver. If the balance is too delicate, requiring very small elevator changes for trim variations, if there is friction or binding in the system, or even effective backlash, an apparent instability may be created, the effects of which are similar to those of the actual one.

Tests have shown that an airplane may have satisfactory flying qualities and still be dynamically unstable; that is, the oscillations may increase in amplitude. It has not been established that an airplane can be made completely dynamically stable without adversely affecting other qualities. It does seem important, however, to have positive stability in the range where the airplane may be flown hands off. This range will cover certain emergency flight conditions. Inasmuch as the take-off, the gliding, and the landing conditions require the constant attention of the pilot, the cruising condition becomes the one for which dynamic stability seems most important at present.

LATERAL STABILITY

The problem of lateral stability is not so well understood and is at present of secondary importance to that of longitudinal stability. Lateral stability has to do with stability in roll but cannot be dissociated from stability in yaw. All airplanes lose the stability in roll of the wing itself at some angle of attack and, with modern airplanes, this angle is being reduced even below that for maximum lift. This phase involves the stalling problem which is discussed later. At all normal angles of attack the stability of the airplane in roll is dependent on dihedral effect, which is not entirely defined by the magnitude of the dihedral angle of the wing. At present, it is certain only that some positive dihedral effect is desired. This requirement means that the roll due to sideslip or yaw should tend to raise the advanced wing. There should always be a tendency, however, to return to a laterally level attitude, regardless of the displacement.

The relationship of stability in yaw to stability in roll has been observed to be as important as their individual values. The desirable range of the ratio appears to be quite narrow. Too little dihedral effect, though positive, leads to spiral instability. A small

lateral disturbance causes sideslip into which, due to stability in yaw, the nose turns before the wing can raise, resulting in a further lowering of the wing by roll due to yawing. The airplane deviates more and more from straight flight and travels an increasingly tight spiral path. This tendency is characteristic of all airplanes tested to date, when trimmed for a given speed, following which all controls are freed. Flaps and power aggravate this condition. Spiral instability has not been particularly troublesome to date because the original deviations are slow and are easily corrected by small use of the control.

In all airplanes tested thus far, the stability in yaw has been observed to predominate so strongly as to overcome, particularly in sideslip, the rudder effect that the pilot can exert. At low speeds, flaps down, the loss in rudder effect is due mainly to blanketing. Spiral instability against full opposite rudder thus exists in both cases. Fortunately, these apparent failings in lateral stability are offset by good lateral control. The airplanes are not unpleasant to fly or to control but do require constant attention to rudder and ailerons.

Such a case of too great a dihedral effect was encountered some years ago. A slight touch of the rudder produced more roll than it did change of heading. The aileron effectiveness was reversed due to their yawing moments and finally a lateral oscillation, difficult to control, caused the airplane to tend to turn around and fly in the opposite direction. The flight was of short duration.

The foregoing discussion indicates that the desirable magnitude of lateral stability is very uncertain. Some lateral stability is desirable, but an excessive amount would probably be definitely harmful. The necessity of fighting controls in rough gusty air is due to excessive rather than to insufficient stability in roll or yaw or both. There is considerable difference of opinion as to the degree to which banking and turning should be automatically dependent upon each other, and to what extent their control should depend upon the pilot.

The Stall

The stall is primarily an angle-of-attack phenomenon and can be produced and relieved by the same control that governs angle of attack, namely, the elevators. It is the opinion of the author that, if the longitudinal-stability and the lateral-stability characteristics were as they should be, the importance of the stall would become of secondary importance.

All types of airplanes lose their rolling stability more or less sharply at some angle of attack. The presence of this unstable condition near maximum lift with its resulting altitude loss, in addition to effectively increasing the landing speed, constitutes one of the greatest dangers attached to stalling.

The angle of attack at which damping in roll of the wing disappears becomes smaller as the taper ratio increases and flaps are lowered. It should not be within the power of the pilot to produce inadvertently such angles of attack. With this restriction in mind, the longitudinal stability and the control at high angles of attack and the manner in which they do or do not produce control-force and position warnings, assume great importance. Lacking the warning that such characteristics can produce, some active warning device is definitely required.

Regarding the actual stall of the wing itself, it seems to matter little where the airflow breakdown originates but more on how it grows. The rate of its spread is an indication of its severity.

The power-off stalling characteristics are relatively mild and longitudinal stability is usually at its best. Any tendency of the wing taper to produce tip stalling is counteracted by the interference set up by the engine nacelles and the fuselage. The flow over the center sections breaks down progressively as the angle of attack is increased and, even though small portions of the tip may stall, a comparatively mild roll-off results. The condition is but slightly worse when flaps are down.

Partial or full power materially aggravates the case. The airplanes approach the stall with little or no change in control feed or vibration. The slipstream over the central portion of the wing delays the flow breakdown at that section until well after it has started and grown to cover large areas at the tips. A rapid roll to either side may then be expected to occur. The stalling characteristics of the largest airplanes appear no different generally from those of similar small ones.

The wing stalling characteristics do differ somewhat with different airplanes. The factors on which they depend seem to be wing plan form, wing twist, airfoil section characteristics, local interferences, and slipstream. All these factors are being studied in detail in flight. It bears mentioning that the opinions of the pilots, and also of trained observers and passengers for that matter, cannot be relied upon to judge the angles of pitch and roll assumed by a large airplane when stalled. Most observers overestimate the angles by about 100 percent.

Conclusion

It is the opinion of the author that static longitudinal stability, most particularly at low speeds, is of prime importance to safety in flight. The desirable degree of dynamic longitudinal stability and lateral stability cannot be as clearly defined but they should at least be positive without severe oscillations. There is a feeling that spiral stability would be very desirable but this has not been fully substantiated. Stalling characteristics, although they are of interest and should be made as mild as possible, become relatively unimportant if the other characteristics are as they should be to make this unproductive flight range only remotely possible.

Two-Dimensional Subsonic Flow of Compressible Fluids

HSUE-SHEN TSIEN

California Institute of Technology

SUMMARY

The basic concept of the present paper is to use a tangent line to the adiabatic pressure-volume curve as an approximation to the curve itself. First, the general characteristics of such a fluid are shown. Then in Section I a theory is developed which can be applied to flows with velocities approaching that of sound, whereas the theory of Demtchenko and Busemann only give an approximation for flows with velocities smaller than one-half of the sound velocity. This is done by a generalization of the method of approximation to the adiabatic relation by a tangent line, conceived jointly by Th. von Kármán and the author. The theory is put into a form by which, knowing the incompressible flow over a body, the compressible flow over a similar body can be calculated. The theory is then applied to calculate the flow over elliptic cylinders. In Section II the work of H. Bateman is applied to this approximate adiabatic fluid and the results obtained are essentially the same as those obtained in Section I.

INTRODUCTION

Assuming that the pressure is a single-valued function of density only, the equations of two-dimensional irrotational motion of compressible fluids can be reduced to a single non-linear equation of the velocity potential. In the supersonic case, that is, in the case when flow velocity is everywhere greater than that of local sound velocity, the problem is solved by Meyer and Prandtl and Busemann using the method of characteristics. The essential difficulty of this problem lies in the subsonic case, that is, in the case when flow velocity is everywhere smaller than but near the local sound velocity, because then the method of characteristics cannot be used. Glauert and Prandtl[1] treated the case when the disturbance of parallel rectilinear flow, due to the presence of a solid body, is small. They were then able to linearize the differential equation for the velocity potential and obtain an equation very similar to that for incompressible fluids. But there are usually stagnation points either on the surface of the body or in the field of flow, where the disturbance is no longer small. Hence, it is doubtful whether the linear theory can be applied to the flow near a stagnation point. For the same reason, the theory breaks down in the case of bodies whose dimension across the stream is not small compared with the dimension parallel to the stream.

To treat these cases Janzen and Rayleigh developed the method of successive approximations. This method was put into a more convenient form by Poggi and Walther. Recently, Kaplan[2] treated the case of flow over Joukowsky air-foils and elliptic cylinders using Poggi's method. However, the method is rather tedious and the convergence very slow if the local velocity of sound is approached.

Molenbroek and Tschapligin suggested the use of the magnitude of velocity w and inclination β of velocity to a chosen axis as independent variables, and were thus able to reduce the equation of velocity potential to a linear equation. This equation was solved by Tschapligin. The solution is essentially a series, each term of which is a product of a hypergeometric function of w and a trigonometric function of β. The main difficulty in practical application of this solution is to obtain a proper set of boundary conditions in the plane of independent variables w, β and to put the solution in a closed form.

Tschapligin has shown that a great simplification of the equation in the hodograph plane results if the ratio of the specific heats of the gas is equal to -1. Since all real gases have their ratio of specific heats between 1 and 2, the value -1 seems without practical significance. Demtchenko[3] and Busemann[4] clarified the meaning of this specific value of -1. They found that this really means to take the tangent of the pressure-volume curve as an approximation to the curve itself. However, they limit themselves to the use of the tangent at the state of the gas corresponding to the stagnation point of flow. As a result their theory can only be applied to a flow with velocities up to about one-half the velocity of sound. Recently, during a discussion with Th. von Kármán he suggested to the author that the theory can be generalized by using the tangent at the state of the gas corresponding to undisturbed parallel flow. Thus the range of usefulness of the theory can be greatly extended. This is carried out in the first section of the present paper. This theory, based upon Demtchenko and Busemann's work, is then applied to the case of flow over elliptic cylinders and the results compared with those of Hooker[5] and Kaplan.[2] Furthermore, results calculated by Glauert-Prandtl linear theory are also included for comparison.

Recently, Bateman[6] demonstrated a remarkable reciprocity between two fields of flow, of two fluids related by a certain point transformation. It is shown in the second section of this paper that the flow of an incompressible fluid and the flow of a compressible fluid approximated by the use of the tangent to adiabatic pressure-volume curve can be interpreted as such a

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point transformation. It is therefore possible to obtain a solution for compressible flow whenever a solution of incompressible flow is known. This transformation from the flow of an incompressible fluid to the flow of a compressible fluid is found, however, to be essentially the same as that developed from Demtchenko and Busemann's work.

Approximation to the Adiabatic Relation

If p is the pressure, v is the specific volume and γ is the ratio of specific heats of a gas, the adiabatic relation pv^γ = constant is a curve in the p-v plane as shown in Fig. 1(a). The conditions near the point p_1, v_1 which

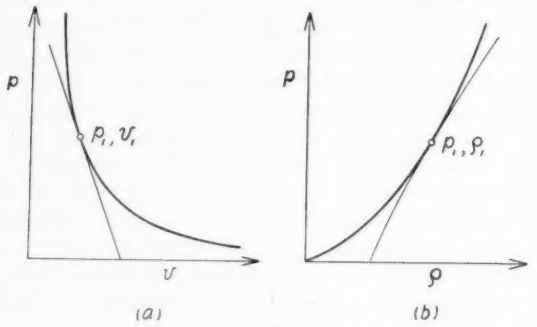


Fig. 1. Approximation to the adiabatic p-v relation by means of a tangent.

correspond to a state of undisturbed flow can be approximated by the tangent to the curve at that point. The equation of the tangent at this point can be written

$$p_1 - p = C(v_1 - v) = C(\rho_1^{-1} - \rho^{-1}) \tag{1}$$

where C is the slope of the tangent and ρ is the density of the fluid. The slope C must be equal to the slope of the curve at the point p_1, v_1. Therefore,

$$C = \left(\frac{dp}{dv}\right)_1 = \left(\frac{dp}{d\rho}\frac{d\rho}{dv}\right)_1 = -\left(\frac{dp}{d\rho}\right)_1 \rho_1^2 = -a_1^2\rho_1^2$$

where a_1 is the sound velocity corresponding to the conditions p_1, v_1. Thus Eq. (1) can be written

$$p_1 - p = a_1^2\rho_1^2(\rho^{-1} - \rho_1^{-1}) \tag{2}$$

This is an approximation to the true adiabatic pressure-density relation, and is shown in Fig. 1(b) together with the true adiabatic relation.

The generalized Bernoulli theorem for compressible fluids is:

$$w_2^2 - w_3^2 = 2\int_2^3 dp/\rho \tag{3}$$

where w is the velocity of the gas and the subscripts 2 and 3 denote two different states of the fluid. By substituting Eq. (2) into Eq. (3),

$$w_2^2 - w_3^2 = a_1^2\rho_1^2(\rho_2^{-2} - \rho_3^{-2}) \tag{4}$$

Now if $w_3 = 0$, $w_2 = w$, $\rho_3 = \rho_0$, and $\rho_2 = \rho$, with the subscript 0 denoting the state of the fluid corresponding to the stagnation point of flow, Eq. (4) gives

$$\frac{a_1^2\rho_1^2}{\rho_0^2} + w^2 = \frac{\rho_1^2 a_1^2}{\rho^2} \tag{5}$$

If the square of sound velocity a^2 is, as usual, defined as the derivative of p with respect to ρ, Eq. (2) gives

$$a^2\rho^2 = \rho^2 dp/d\rho = a_1^2\rho_1^2 = \text{constant} \tag{6}$$

Therefore, Eq. (5) can be written as:

$$(\rho/\rho_0)^2 = 1 - (w/a)^2 \tag{7}$$

Similarly,

$$(\rho_0/\rho)^2 = 1 + (w/a_0)^2 \tag{8}$$

It is interesting to note that from Eq. (8) the density decreases as the velocity increases, as may be expected. Therefore Eq. (6) indicates that the local velocity of sound increases as the velocity increases. This behavior is opposite to that of a real gas, since in the case of an adiabatic flow of a real gas it is well known that the temperature of the gas decreases as the velocity increases; thus the local sound velocity, being proportional to the square root of the temperature, also decreases. However, in the present approximate theory, the ratio w/a or the Mach Number, still increases as the velocity increases, as can be seen from Eq. (7). But this ratio only reaches the value unity when $\rho = 0$, or from Eq. (8), when $w = \infty$. It is thus seen that the entire regime of flow is subsonic and the differential equation of the velocity potential is always of an elliptic type, *i.e.*, always of the same type as the differential equation of the velocity potential of incompressible fluids. This is the reason why the complex representation of the velocity potential and the stream function is possible for all cases, as will be shown in the following paragraphs. However, one should realize that the portion of the tangent that could be used as an approximation to the true adiabatic relation is that portion which lies in the first quadrant. Thus the upper velocity limit for practical application of the theory occurs at $p = 0$. By using Eqs. (7) and (8) this upper limit is found to be

$$\left(\frac{w}{w_1}\right)_{max.} = \frac{1}{(w_1/a_1)}\sqrt{\left(\frac{p_1}{a_1^2\rho_1} + 1\right)^2 - \left[1 - \left(\frac{w_1}{a_1}\right)^2\right]} \tag{9}$$

Since the point p_1, ρ_1 being the tangent point to the true adiabatic curve, lies on the curve, the relation $a_1^2 = \gamma p_1/\rho_1$ which is true for the adiabatic relation $p\rho^{-\gamma}$ = constant can be used, and Eq. (9) becomes

$$\left(\frac{w}{w_1}\right)_{max.} = \frac{1}{(w_1/a_1)}\sqrt{\left(\frac{1}{\gamma} + 1\right)^2 - \left[1 - \left(\frac{w_1}{a_1}\right)^2\right]} \tag{10}$$

This relation is plotted in Fig. 2 with $\gamma = 1.405$. Since for most practical cases it is not likely that the ratio (w/w_1) will rise to values much higher than 2, p will remain positive, and this theory will be sufficient to give an approximate solution.

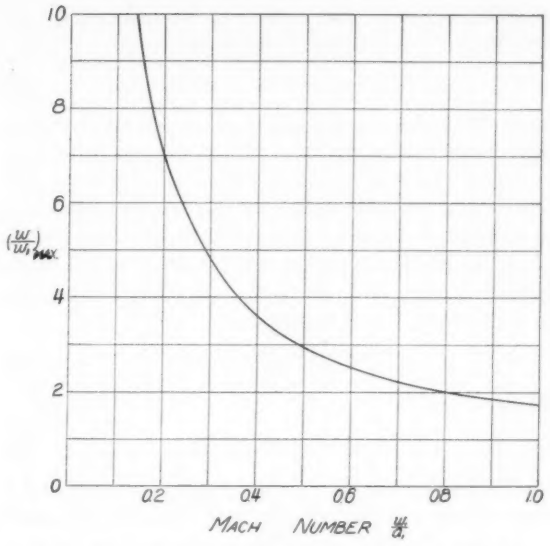


FIG. 2. Relation between the maximum velocity $(w/w_1)_{max.}$ (at which the pressure is zero) and the Mach Number (w_1/a_1).

SECTION I

Hodograph Method

If the flow is irrotational, there exists a velocity potential ϕ such that

$$\partial\phi/\partial x = u,\ \partial\phi/\partial y = v \tag{11}$$

where u, v are the components of w in the x and y direction, respectively. The equation of continuity

$$\frac{\partial}{\partial x}\left(\frac{\rho}{\rho_0}u\right) + \frac{\partial}{\partial y}\left(\frac{\rho}{\rho_0}v\right) = 0$$

will be satisfied, if the stream function ψ is introduced such that:

$$u\rho/\rho_0 = \partial\psi/\partial y,\ -v\rho/\rho_0 = \partial\psi/\partial x \tag{12}$$

If the angle of inclination of the velocity w to the x axis is β, Eqs. (11) and (12) give:

$$\begin{aligned} d\phi &= w\cos\beta dx + w\sin\beta dy \\ d\psi &= -w(\rho/\rho_0)\sin\beta dx + w(\rho/\rho_0)\cos\beta dy \end{aligned} \tag{13}$$

Solving for dx and dy,

$$\begin{aligned} dx &= \frac{\cos\beta}{w}d\phi - \frac{\sin\beta}{w}\frac{\rho_0}{\rho}d\psi \\ dy &= \frac{\sin\beta}{w}d\phi + \frac{\cos\beta}{w}\frac{\rho_0}{\rho}d\psi \end{aligned} \tag{14}$$

As long as the correspondence between the physical and hodograph plane is one to one, or mathematically $\partial(x, y)/\partial(u, v) \neq 0$; x and y can be expressed as functions of w, β, and ϕ and ψ as function of w, β. Thus,

$$\begin{aligned} d\phi &= \phi_w' dw + \phi_\beta' d\beta \\ d\psi &= \psi_w' dw + \psi_\beta' d\beta \end{aligned} \tag{15}$$

where primes indicate the derivative with respect to the independent variables indicated as subscripts. Substituting Eq. (15) into Eq. (14), the following expressions for dx and dy are obtained:

$$\begin{aligned} dx = &\left(\frac{\cos\beta}{w}\phi_w' - \frac{\sin\beta}{w}\frac{\rho_0}{\rho}\psi_w'\right)dw + \\ &\left(\frac{\cos\beta}{w}\phi_\beta' - \frac{\sin\beta}{w}\frac{\rho_0}{\rho}\psi_\beta'\right)d\beta \\ dy = &\left(\frac{\sin\beta}{w}\phi_w' + \frac{\cos\beta}{w}\frac{\rho_0}{\rho}\psi_w'\right)dw + \\ &\left(\frac{\sin\beta}{w}\phi_\beta' + \frac{\cos\beta}{w}\frac{\rho_0}{\rho}\psi_\beta'\right)d\beta \end{aligned} \tag{16}$$

Since the left-hand side of Eqs. (16) are exact differentials, the reciprocity relation can be applied, and, therefore,

$$\begin{aligned} &\frac{\partial}{\partial\beta}\left(\frac{\cos\beta}{w}\phi_w' - \frac{\sin\beta}{w}\frac{\rho_0}{\rho}\psi_w'\right) = \\ &\qquad\frac{\partial}{\partial w}\left(\frac{\cos\beta}{w}\phi_\beta' - \frac{\sin\beta}{w}\frac{\rho_0}{\rho}\psi_\beta'\right) \\ &\frac{\partial}{\partial\beta}\left(\frac{\sin\beta}{w}\phi_w' + \frac{\cos\beta}{w}\frac{\rho_0}{\rho}\psi_w'\right) = \\ &\qquad\frac{\partial}{\partial w}\left(\frac{\sin\beta}{w}\phi_\beta' + \frac{\cos\beta}{w}\frac{\rho_0}{\rho}\psi_\beta'\right) \end{aligned} \tag{17}$$

Carrying out these differentiations and simplifying with the aid of Eq. (7), Eq. (17),

$$\begin{aligned} -\frac{\sin\beta}{w}\phi_w' - \frac{\cos\beta}{w}\frac{\rho_0}{\rho}\psi_w' &= -\frac{\cos\beta}{w^2}\phi_\beta' + \frac{\sin\beta}{w^2}\frac{\rho}{\rho_0}\psi_\beta' \\ \frac{\cos\beta}{w}\phi_w' - \frac{\sin\beta}{w}\frac{\rho_0}{\rho}\psi_w' &= -\frac{\sin\beta}{w^2}\phi_\beta' - \frac{\cos\beta}{w^2}\frac{\rho}{\rho_0}\psi_\beta' \end{aligned} \tag{18}$$

Solving for ϕ_w' and ψ_β',

$$\begin{aligned} \phi_w' &= -\frac{\rho}{\rho_0}\frac{1}{w}\psi_\beta' \\ \phi_\beta' &= \frac{\rho_0}{\rho}w\psi_w' \end{aligned} \tag{19}$$

Eq. (19) can be further simplified by introducing a new variable ω, such that

$$d\omega = \frac{\rho}{\rho_0}\frac{dw}{w} \tag{20}$$

Then Eq. (19) becomes

$$\phi_\omega' = -\psi_\beta',\ \phi_\beta' = \psi_\omega' \tag{21}$$

This can be easily recognized as the Cauchy-Riemann differential equation, and thus $\phi + i\psi$ must be an analytic function of $\omega - i\beta$. However, for convenience of calculation, another new set of independent variables

$U = W\cos\beta$, $V = W\sin\beta$ are introduced where $W = a_0 e^{\omega}$. Then Eq. (21) can be written as

$$\begin{aligned} \partial\phi/\partial U &= \partial\psi/\partial(-V) \\ \partial\phi/\partial(-V) &= -\partial\psi/\partial U \end{aligned} \tag{22}$$

Integrating Eq. (20),

$$W = 2a_0 w/\left(\sqrt{a_0^2 + w^2} + a_0\right) \tag{23}$$

and

$$w = 4a_0^2 W/(4a_0^2 - W^2) \tag{24}$$

Substituting into Eq. (8), the following expression for the density ratio ρ_0/ρ is obtained:

$$\rho_0/\rho = (4a_0^2 + W^2)/(4a_0^2 - W^2) \tag{25}$$

Eqs. (22), (23), (24), and (25) are the basic equations of the present theory. Eq. (22) is the Cauchy-Riemann differential equation, and thus the complex potential $F = \phi + i\psi$ must be an analytic function of $\overline{W} = U - iV$, or:

$$\begin{aligned} \phi + i\psi &= F(U - iV) = F(\overline{W}) \\ \phi - i\psi &= \overline{F}(U + iV) = \overline{F}(W) \end{aligned} \tag{26}$$

In Eq. (26), $\overline{W}$ and $\overline{F}$ are the complex conjugates of W and F, respectively.

It is now necessary to find the values of x and y corresponding to a given set of values of U and V, *i.e.*, to find the transformation from the hodograph plane to the physical plane. By using Eqs. (24) and (25), Eq. (14) can be written

$$\begin{aligned} dx &= \frac{U\cdot d\phi}{W^2}\left(1 - \frac{W^2}{4a_0^2}\right) - \frac{V\cdot d\psi}{W^2}\left(1 + \frac{W^2}{4a_0^2}\right) \\ dy &= \frac{V\cdot d\phi}{W^2}\left(1 - \frac{W^2}{4a_0^2}\right) + \frac{U\cdot d\psi}{W^2}\left(1 + \frac{W^2}{4a_0^2}\right) \end{aligned} \tag{27}$$

where $W^2 = U^2 + V^2$. These equations can be combined into one equation by means of Eq. (26). Thus,

$$dz = dx + i dy = \frac{dF}{\overline{W}} - \frac{W\cdot d\overline{F}}{4a_0^2} \tag{28}$$

Hence, if an analytic function $F(\overline{W})$ is given for each value of W, the corresponding real velocity w can be calculated by Eq. (24). Then the coordinate of the point in the physical plane at which this velocity occurs can be calculated by integrating Eq. (28). The pressure at this point is then given by Eq. (2). However, using this procedure, it is not possible to predict whether the chosen function $F(\overline{W})$ will give the desired shape of the solid boundary and flow pattern. In other words, this procedure, in common with all hodograph methods, still suffers the difficulty of boundary conditions.

Transformation from Incompressible Flow to Compressible Flow

However, using the simple relation of Eq. (28) the resulting shape of the body can be ascertained approximately by starting with the function:

$$F(\overline{W}) = \phi + i\psi = W_1 G(\zeta) \tag{29}$$

where W_1 is the transformed undisturbed velocity to be interpreted by Eq. (23), and ζ is the complex coordinate $\xi + i\eta$. This function is so chosen as to give the flow of an incompressible fluid over the desired body shape in coordinates ξ and η. The real velocity in the ζ plane of the incompressible fluid is interpreted as the transformed velocity W in the hodograph plane for the compressible fluid. It is known that

$$\overline{W} = W_1 dG(\zeta)/d\zeta \tag{30}$$

Thus,

$$W = W_1 d\overline{G}(\bar{\zeta})/d\bar{\zeta} \tag{31}$$

where $\overline{G}$ and $\bar{\zeta}$ are the complex conjugates of G and ζ, respectively. With Eqs. (30) and (31), Eq. (28) gives

$$dz = d\zeta - \lambda[d\overline{G}/d\bar{\zeta}]^2 d\bar{\zeta}$$

where $\lambda = {}^1/_4(W_1/a_0)^2$. Integrating,

$$z = \zeta - \lambda \int [d\overline{G}/d\bar{\zeta}]^2 d\bar{\zeta} \tag{32}$$

Therefore, the complex coordinate in the physical plane of the compressible fluid is equal to the corresponding complex coordinate in the physical plane of the incompressible fluid plus a correction term. Since this correction term is usually small, the resulting shape of the body will be quite similar to the one in the incompressible fluid. The factor λ in the correction term depends upon the Mach Number of the undisturbed flow only. This can be shown by means of Eqs. (7), (8), and (23), because from those equations the following relation is obtained:

$$\lambda = \frac{1}{4}\left(\frac{W_1}{a_0}\right)^2 = \frac{(w_1/a_1)^2}{[1 + \sqrt{1 - (w_1/a_1)^2}]^2} \tag{33}$$

where w_1/a_1 is the Mach Number of the undisturbed flow. The values of λ for different Mach Numbers w_1/a_1 are plotted in Fig. 3.

To calculate the velocity in the physical plane, $\overline{W}$ is first obtained from Eq. (30) and then with Eq. (23):

$$\frac{w}{w_1} = \frac{|W|}{W_1}\,\frac{1 - \lambda}{1 - \lambda(|W|/W_1)^2} \tag{34}$$

If the pressure coefficient $\tilde{\omega}$ at any point is defined as $\tilde{\omega} = (p - p_0)/({}^1/_2\rho_1 w_1^2$, then by using Eq. (2), the following relation is obtained:

$$\tilde{\omega} = (1 + \lambda)\,\frac{1 - (|W|/W_1)^2}{1 - \lambda(|W|/W_1)^2} \tag{35}$$

Flow over Elliptic Cylinders

The theory will now be applied to calculate the flow over an elliptic cylinder at zero angle of attack. The

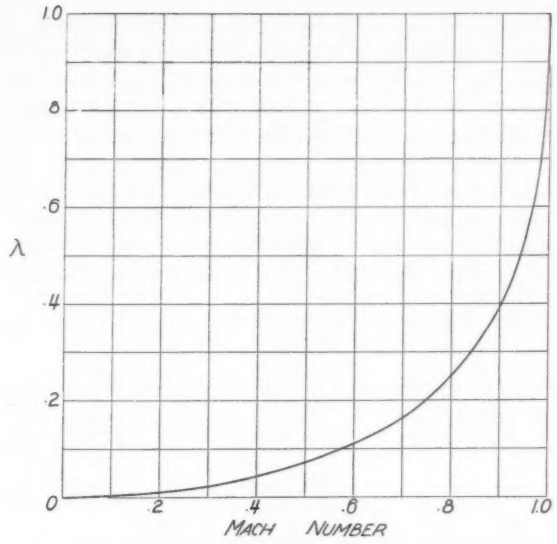


FIG. 3. Variation of the parameter λ of transformation from incompressible flow to compressible flow with the Mach Number w_1/a_1.

incompressible flow over an elliptic cylinder in the complex coordinate ζ can be obtained by applying Joukowsky's transformation to the flow over a circular cylinder in the complex coordinate ζ' with the center of the circle located at the origin of the ζ' plane. Therefore, the function $F(\overline{W})$ or $W_1G(\zeta)$ can be written as:

$$\begin{aligned} F &= W_1(\zeta' + b^2/\zeta) \\ \overline{F} &= W_1(\overline{\zeta}' + b^2/\overline{\zeta}') \end{aligned} \tag{36}$$

where b is the radius of the circle in the ζ' plane. The Joukowsky transformation is:

$$\zeta = \zeta' + 1/\zeta' \tag{37}$$

It is convenient to carry out the computation by using the ζ' coordinates. Thus Eq. (32) is rewritten in the following form:

$$z = \left(\zeta' + \frac{1}{\zeta'}\right) - \lambda \int \left(\frac{d\overline{G}}{d\overline{\zeta}'}\right)^2 \frac{d\overline{\zeta}'}{d\overline{\zeta}/d\overline{\zeta}'} \tag{38}$$

If only the conditions over the surface of the elliptic cylinder are concerned, then:

$$\zeta' = be^{i\theta}, \ \overline{\zeta}' = be^{-i\theta} \tag{39}$$

where θ is the argument as shown in Fig. 4 and b is the radius of the circular section in the ζ' plane which determines the thickness ratio of the elliptic section in the ζ plane. Substituting Eqs. (36), (37), and (39) into Eq. (38), and carrying out the integration, the following expressions for the x and y coordinates corresponding to ζ' are obtained by separating the real and imaginary parts:

$$x = \left(b + \frac{1}{b}\right)\cos\theta - \lambda\left[b(1+b^2)\cos\theta + \frac{(b^2-1)^2}{4}\log\frac{(b^2-1)^2 + 4b^2\sin^2\theta}{(b^2 + 2b\cos\theta + 1)}\right]$$

$$y = \left(b - \frac{1}{b}\right)\sin\theta + \lambda\left[b(1-b^2)\sin\theta + \frac{(b^2-1)^2}{2}\tan^{-1}\frac{2b\sin\theta}{b^2-1}\right] \tag{40}$$

The horizontal and vertical semi-axis of the approximately elliptic section can then be calculated by substituting $\theta = 0$ and $\theta = \pi/2$, respectively, into Eq. (40). The thickness ratio δ is thus obtained as:

$$\delta = \left(\frac{b^2-1}{b^2+1}\right) \times \frac{1 + \lambda\left[-b^2 + \frac{b(b^2-1)}{2}\tan^{-1}\frac{2b}{b^2-1}\right]}{1 - \lambda\left[b^2 + \frac{b(b^2-1)}{2}\left(\frac{b^2-1}{b^2+1}\right)\log\left(\frac{b-1}{b+1}\right)\right]} \tag{41}$$

For a given thickness ratio and Mach Number for undisturbed flow, the value of λ is first computed by means of Eq. (33), and then Eq. (41) is solved graphically for b.

After b is obtained, the coordinate x and y for each value of θ can be computed by using Eq. (40). It is fortunate that the values of x, y so obtained lie very close to the true elliptic section. Hence, the velocity and the pressure distribution obtained by using Eqs. (34) and (35) are considered as those over the true elliptic sections.

Calculations for two thickness ratios, $\delta = 0.5$ and $\delta = 0.1$, are carried out and the results shown in Figs. 5 and 6, together with those of Kaplan.[2] Hooker's results[5] are very close to those of Kaplan. Computations are also carried out using the more simple theory of Glauert and Prandtl,[1] and the results are included in Figs. 5 and 6 in order to compare with those of Kaplan and the present theory.

The difference between the various theories lies in the assumptions which are made to simplify the calculations. Glauert and Prandtl assumed that the disturbance introduced by the solid body to the parallel flow is small. In other words, they treated the flow over a body of small thickness ratio. On the other hand, Kaplan and Hooker assume that the Mach Number of the undisturbed flow is small, so that terms containing

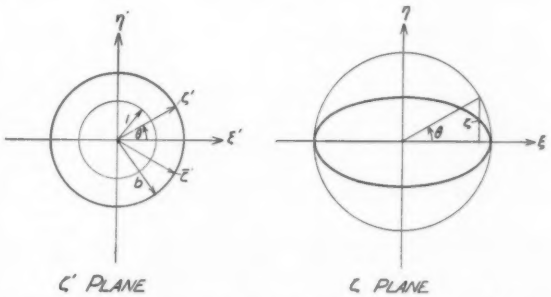


FIG. 4. Notations used in calculating the flow over an elliptical cylinder.

the third and higher powers of the Mach Number can be neglected. The present theory is essentially an improvement of the Glauert-Prandtl theory, so that the effect of large disturbances to the parallel flow is approximately taken into account. Therefore, for flow over thin sections at high Mach Numbers, the result of the present theory should agree well with the Glauert-Prandtl theory, especially at points not too close to the stagnation point. The results of Kaplan and Hooker should show smaller effect of the compressibility due to their second order approximation. For flow over thick sections at lower Mach Numbers, the situation is reversed. In this case results of the present theory should give better agreement with the results obtained by Kaplan and Hooker than with those obtained from the Glauert-Prandtl theory. The above reasoning is substantiated by Figs. 5 and 6.

Critical Velocities for Elliptic Cylinders

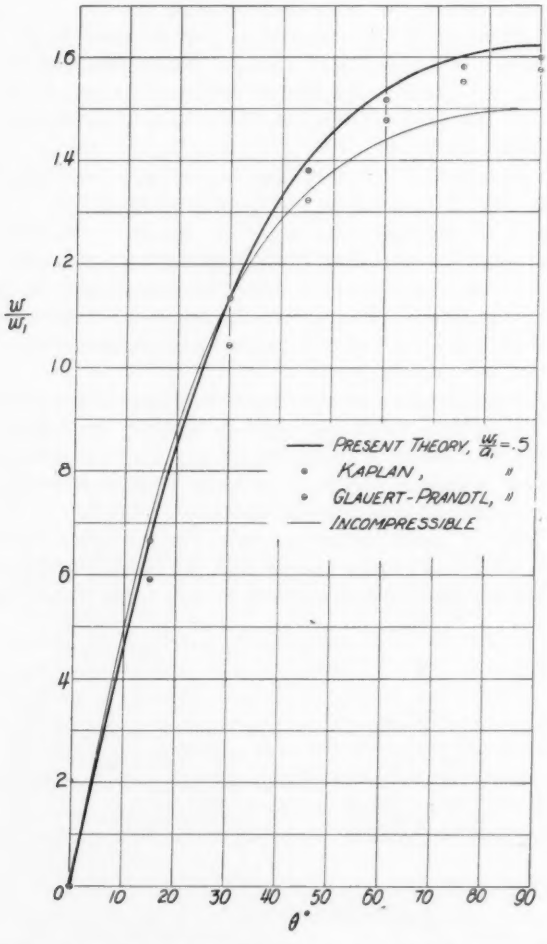
If the velocity of flow over a body is gradually increased, the maximum local velocity in the field will also be increased. When the maximum local velocity reaches the local velocity of sound, shock waves appear and the drag of the body suddenly increases. This velocity is, therefore, of considerable interest to practical engineers and is usually referred to as the critical velocity of the body. It is shown by Kaplan[2] and others that at this critical condition the ratio of maximum velocity of $w_{max.}$ in the field to that of the undisturbed velocity w_1 is related to the Mach Number w_1/a_1 of the undisturbed flow in the following manner:

$$\frac{w_{max.}}{w_1} = \left[\frac{2}{\gamma+1}\,\frac{1}{(w_1/a_1)^2} + \frac{\gamma-1}{\gamma+1}\right]^{1/2} \tag{42}$$

$w_{max.}$ in the flow over an elliptic cylinder at zero angle of attack occurs at the top of the cylinder. Using Eqs. (34) and (33) the value of $w_{max.}/w_1$ is found to be

$$\frac{w}{w_1} = \frac{2b^2/(b^2+1)}{1 + \dfrac{\left[1-\left(\dfrac{2b^2}{b^2+1}\right)^2\right]\left(\dfrac{w_1}{a_1}\right)^2}{2\left(1+\sqrt{1-\left(\dfrac{w_1}{a_1}\right)^2}\right)\sqrt{1-\left(\dfrac{w_1}{a_1}\right)^2}}} \tag{43}$$

Equating Eqs. (42) and (43) the equation for calculating the critical Mach Number (w_1/a_1) of the undisturbed flow for each value of b is



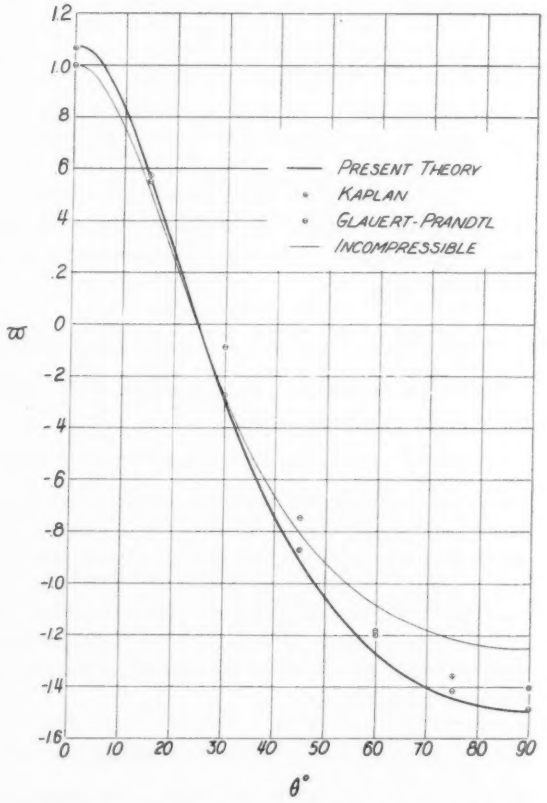


FIG. 5. Flow over an elliptical cylinder with thickness ratio $\delta = 0.5$ at Mach Number = 0.5. (a) Velocity distribution; (b) Pressure distribution.

$$\left[\frac{2}{\gamma+1}\,\frac{1}{(w_1/a_1)_{crit.}}+\frac{\gamma-1}{\gamma+1}\right]^{1/2}=\frac{2b^2/(b^2+1)}{1+\dfrac{\left[1-\left(\dfrac{2b^2}{b^2+1}\right)^2\right]\left(\dfrac{w_1}{a_1}\right)^2_{crit.}}{2\left(1+\sqrt{1-\left(\dfrac{w_1}{a_1}\right)^2_{crit.}}\sqrt{1-\left(\dfrac{w_1}{a_1}\right)^2_{crit.}}\right)}} \tag{44}$$

Knowing $(w_1/a_1)_{crit.}$ for each value of b the corresponding value of δ can be calculated by means of Eqs. (34) and (41). Fig. 7 shows the result of this calculation with Kaplan's value included for comparison. It is seen that the critical Mach Number is lower than that obtained by Kaplan. This lower value of the critical Mach Number indicates a more pronounced effect of compressibility of a fluid and is consistent with the results shown in Figs. 5 and 6.

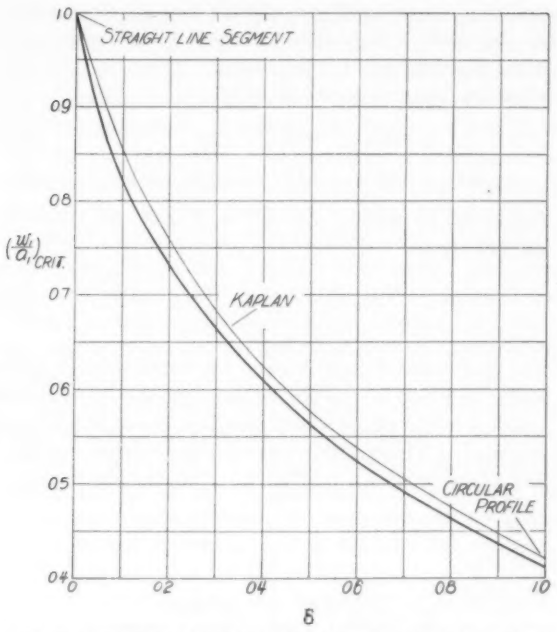


FIG. 7. Variation of critical Mach number $(w_1/a_1)_{crit.}$ of an elliptical cylinder with thickness ratio δ.

SECTION II

The Use of Lift and Drag Functions

If two new functions X and Y are defined by:

$$\begin{aligned} p_0 dX &= pdy + \rho_0 ud\psi \\ p_0 dY &= \rho_0 vd\psi - pdx \end{aligned} \tag{45}$$

Assuming that the flow is irrotation, it can be shown by means of Eqs. (11) and (12) that the following relations hold:

$$\begin{aligned} p_0 dX &= (p+\rho u^2)dy - \rho uvdx = (p+\rho w^2)dy - \rho vd\phi \\ p_0 dY &= \rho uvdy - (p+\rho v^2)dx = \rho ud\phi - (p+\rho w^2)dx \end{aligned} \tag{46}$$

It is seen that by integrating Eq. (46) along any closed boundary, it will give the resultant of the pressure forces acting along the boundary and the rate of increase of momentum of the fluid passing out of the boundary. If there is a solid body in this boundary,

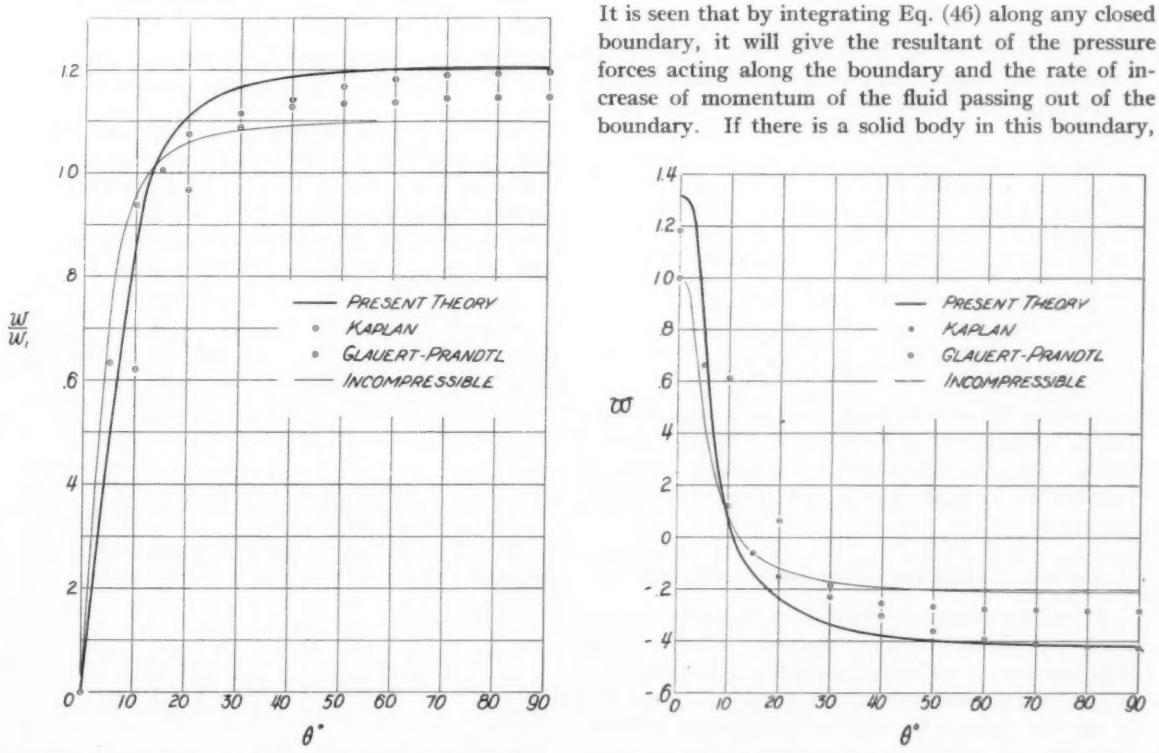


FIG. 6. Flow over an elliptical cylinder with thickness ratio $\delta = 0.1$ at Mach Number = 0.857. (a) Velocity distribution; (b) Pressure distribution.

then this integral will give the lift and the drag acting on the body. Therefore, X and Y are sometimes called the drag and lift functions. From Eq. (46) the following relations can be deduced:

$$p_0(vdX - udY) = pd\phi \tag{47}$$

$$p_0(\rho/\rho_0)(udX + vdY) = (p + \rho w^2)d\psi \tag{48}$$

Therefore, by writing $\partial\phi/\partial X = R$ and $\partial\phi/\partial Y = S$, Eq. (47) gives

$$R = \frac{\partial\phi}{\partial X} = \frac{p_0}{p}v, \quad S = \frac{\partial\phi}{\partial Y} = -\frac{p_0}{p}u \tag{49}$$

The quantities R and S have the dimension of a velocity and can be considered as components of a new velocity in the plane whose coordinates are denoted by X and Y. This relation between the xy plane and the XY plane is shown in Fig. 8. It is thus seen that if

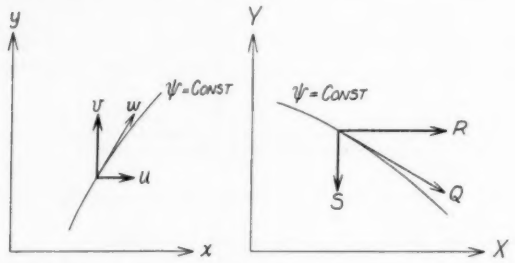


FIG. 8. Relation of the velocity components in the xy plane and XY plane.

the undisturbed flow in the xy plane is in the positive x direction, the undisturbed flow in the XY plane will be in the negative Y direction. Furthermore, if σ is defined as

$$\sigma/\sigma_0 = p\rho/\rho_0(p + \rho w^2) \tag{50}$$

Eq. (48) gives:

$$\frac{\sigma}{\sigma_0}R = -\frac{\partial\psi}{\partial X} = -\frac{u\rho/\rho_0}{(p + \rho w^2)/p_0}$$

$$\frac{\sigma}{\sigma_0}S = \frac{\partial\psi}{\partial Y} = \frac{v\rho/\rho_0}{(p + \rho w^2)/p_0} \tag{51}$$

Comparing Eq. (51) with Eq. (12), it is evident that σ can be considered as the density of a fluid in the XY plane. Therefore, there exists a complete reciprocity between the xy plane and the XY plane, as shown by Bateman.[6]

Transformation Starting with Incompressible Flow

So far the relations obtained are general, *i.e.*, they apply to fluids of arbitrary properties. However, since only the flow of incompressible fluids is well known, it would be interesting to find the properties of the fluid in the XY plane if the fluid in the xy plane is incompressible. If the fluid in the xy plane is incompressible, then $\rho/\rho_0 = 1$, and the Bernoulli theorem gives:

$$(p + {}^1/_2\rho w^2)/p_0 = 1 \tag{52}$$

Let P denote the pressure in the XY plane, and Q^2 denote $R^2 + S^2$; then Eq. (3), the generalized Bernoulli theorem, gives:

$${}^1/_2Q^2 + \int dp/\sigma = \text{constant} \tag{53}$$

In view of Eqs. (49), (50), and (52), Eq. (53) can be written in the following form:

$$\frac{1}{\sigma_0}\int \frac{d\left(\frac{\sigma}{\sigma_0}\right)}{\frac{\sigma}{\sigma_0}} \frac{dP}{d\left(\frac{\sigma}{\sigma_0}\right)} + \frac{p_0}{\rho_0}\left(\frac{1}{4\frac{\sigma_2}{\sigma_0^2}} - \frac{1}{4}\right) = \text{constant} \tag{54}$$

By differentiating Eq. (54) with respect to σ/σ_0, multiplying the resulting expression by σ/σ_0 and then integrating with respect to σ/σ_0, the following relation connecting the pressure P and the density σ for the fluid in the XY plane is obtained:

$$P = C - \frac{1}{2}\frac{p_0}{\rho_0}\sigma_0^2\frac{1}{\sigma} \tag{55}$$

where C is the integration constant. Comparing Eq. (55) with the approximate adiabatic relation Eq. (2), also noting Eq. (6), it is evident that Eqs. (55) and (2) are identical, if

$$\frac{1}{2}\frac{p_0}{\rho_0} = A_0^2 = A_1^2\left[1 - \left(\frac{Q_1}{A_1}\right)^2\right] \tag{56}$$

and

$$C = P_1 + \frac{1}{2}\frac{p_0}{\rho_0}\sigma_0^2\frac{1}{\sigma_1}$$

In Eq. (56) A is the velocity of sound in the XY plane, and the subscript 1 refers to the conditions in the undisturbed flow. Hence, Q_1/A_1 is Mach Number of the undisturbed flow.

By using Eqs. (52) and (49) the components of velocity in the XY plane can be expressed as

$$\frac{R}{Q_1} = -\frac{v}{w_1}\frac{1 - \frac{1}{2}\frac{\rho_0}{p_0}w_1^2}{1 - \frac{1}{2}\frac{\rho_0}{p_0}w_1^2\left(\frac{w}{w_1}\right)^2} \tag{57}$$

$$\frac{S}{Q_1} = \frac{u}{w_1}\frac{1 - \frac{1}{2}\frac{\rho_0}{p_0}w_1^2}{1 - \frac{1}{2}\frac{\rho_0}{p_0}w_1^2\left(\frac{w}{w_1}\right)^2}$$

Hence,

$$\frac{Q}{Q_1} = \frac{w}{w_1}\frac{1 - \frac{1}{2}\frac{\rho_0}{p_0}w_1^2}{1 - \frac{1}{2}\frac{\rho_0}{p_0}w_1^2\left(\frac{w}{w_1}\right)^2} \tag{58}$$

The relation between w_1 and Q_1 can then be obtained from Eqs. (56) and (57), that is:

$$\frac{1}{2}\frac{\rho_0}{p_0}w_1^2 = \frac{(Q_1/A_1)^2}{\left[1+\sqrt{1-(Q_1/A_1)^2}\right]^2} = \lambda \qquad (59)$$

Thus Eq. (58) can be rewritten as:

$$\frac{Q}{Q_1} = \frac{w}{w_1}\frac{1-\lambda}{1-\lambda(w/w_1)^2} \qquad (60)$$

Using Eqs. (55), (56) and (50), the pressure coefficient Π in the XY plane, which is defined by $\Pi = (P - P_1) \div {}^1/_2\sigma_1 Q_1^2$, can be expressed as:

$$\Pi = \left(1+\frac{1}{2}\frac{p_0}{\rho_0}w_1^2\right)\frac{1-(w/w_1)^2}{1-\frac{1}{2}\frac{\rho_0}{p_0}w_1^2\,(w/w_1)^2}$$

Substituting the value of λ from Eq. (59) in the above expression, the following relation is obtained:

$$\Pi = (1+\lambda)\frac{1-(w/w_1)^2}{1-\lambda(w/w_1)^2} \qquad (61)$$

To find the coordinates X and Y in terms of x, y, Eq. (46) must be integrated. It is convenient in this case to use the complex potential of the incompressible flow in the xy plane. If

$$\phi + i\psi = w_1 G(x+iy) = w_1 G(z) \qquad (62)$$

then it can be shown with the aid of Eq. (52) that:

$$\overline{Z} = X - iY = i\bar{z} - \frac{1}{2}\frac{\rho_0}{p_0}w_1^2 i\int\left(\frac{dG}{dz}\right)^2 dz$$

where $\bar{z}$ is the complex conjugate of z. Or, writing Z and $\overline{G}$ as the complex conjugates of $\overline{Z}$ and G:

$$e^{i\pi/2}Z = z - \lambda\int\left(\frac{d\overline{G}}{d\bar{z}}\right)^2 d\bar{z} \qquad (63)$$

where the factor $e^{i\pi/2}$ will rotate the Z plane through an angle equal to $\pi/2$ to make the directions of undisturbed flow in the Z plane and in the z plane coincide.

Comparing the set of Eqs. (59), (60), (61), and (63) with the previous set of Eqs. (33), (34), (35), and (32), it is evident that the two sets are identical except the change of notation. Therefore, Bateman's transformation does not give any new results as it leads to the same expressions as those obtained by the hodograph method.

Concluding Remarks

It is shown both in Section I and in Section II that starting from any solution of an incompressible fluid over a solid body, a solution of a nearly adiabatic flow over another approximately similar solid body can be calculated. The transformation from incompressible flow to compressible flow changes the shape of the body a small amount as represented by the correction terms in Eqs. (32) and (63). Thus, in order to investigate the effect of compressibility over the same body, it is necessary to use different functions $G(z)$ for different Mach Numbers, as shown by the example given in Section I. This complicates the calculations to some extent, but the amount of labor involved is probably much less than the successive approximations devised by Janzen, Rayleigh, Poggi, and Walther, especially at higher Mach Numbers.

The main difficulty of the method lies in its application to flow involving circulation, *e.g.*, the flow over a lifting airfoil. Then if the ordinary complex potential function $G(z)$ for the incompressible fluid is used, the correction terms in Eqs. (32) and (63) are no longer single-valued functions, that is, they do not return to their original value by increasing the argument of z by 2π. In other words, the boundary in compressible flow is no longer a closed curve. Therefore, in order to study this type of problem, it is necessary to use a function $G(z)$ which does not give a closed boundary in the incompressible flow, but will give a closed boundary in the compressible flow when the correction term is added. The problem is thus more difficult, and requires further study.

The author expresses his gratitude to Dr. Th. von Kármán for suggesting the subject and for his kindly criticism during the course of the work.

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On the Relation Between Visibility and the Constitution of Clouds and Fog

H. G. HOUGHTON

Massachusetts Institute of Technology

ABSTRACT

Following Koschmeider's method of attack an expression for the daytime visibility within a cloud or fog is derived in terms of the size of the suspended drops and the number of drops in a unit volume of air. A comparison of typical data for clouds and fogs shows that clouds contain from 50 to 500 drops per cc. with an average drop diameter of about 20 microns while fogs contain only 1 to 10 drops per cc. with an average drop size of about 50 microns. Simultaneous observations of the visibility and the fog characteristics reveal a good qualitative agreement with the theory. In clouds the visibility tends to be inversely proportional to the liquid water content, indicating a constant average drop diameter. In fogs the visibility is more nearly inversely proportional to the two-thirds power of the liquid water content which suggests that the number of drops in a unit volume tends to remain constant. The value of Fechner's constant, which represents the threshold contrast between the object and the background, was found to be greater in a fog than when measured in the laboratory and still larger in clouds. It is suggested that this is due to the diffuse boundary between the object and the background in the case of a fog or cloud.

ALTHOUGH it is recognized that clouds influence the visibility in the regions beneath them by virtue of their controlling effect on the general illumination and glare, this paper will be confined to a discussion of the visibility within a cloud or fog.

The effect of the suspended droplets in a fog or cloud is to scatter or diffuse the light, true absorption being negligible in the visible spectrum. It has been shown[1] that the flux scattered by a spherical drop of radius a is given by $2\pi a^2KE$ where E is the flux density of the incident radiation. K is a non-dimensional function of a/λ where λ is the wave length of the light. If n is the number of drops in a cubic centimeter of air the flux density at any distance z from a point where the flux density is E_0 is given by

$$E/E_0 = e^{-2\pi na^2Kz} \tag{1}$$

The ratio E/E_0 is termed the transmission over the distance z. For drops of the size normally encountered in clouds (a = 2 to 50 microns) and wave lengths within the visible spectrum (λ = 0.4 to 0.7 microns) the value of K is very nearly unity.

Following Koschmieder[2] it is possible to set up an expression for the visibility or more correctly, the visual range, in a cloud or fog. Consider a black body which is viewed against the cloud as a background. The object will have an apparent brightness due to the scattered light which reaches the eye from the pyramid subtended by the object. If B_0 is the apparent brightness of the object and B_b is the brightness of the background, the object will just be visible when

$$(B_b - B_0)/B_b = \epsilon \tag{2}$$

where ϵ is Fechner's constant, which normally has a value of from 0.01 to 0.02.

The light scattered by a drop illuminated by a plane wave is not distributed uniformly in all directions. Most of the scattered light is confined within a relatively small solid angle centering around the direction of propagation of the incident wave. However, due to multiple scattering of the sunlight within a cloud of considerable depth the general illumination within the cloud is almost perfectly diffuse. An individual drop is thus illuminated uniformly from all sides and, consequently, the scattered light is radiated uniformly in all directions. This statement must be modified somewhat if the drop in question is near the ground. In that case there is little radiation received from below and hence a larger portion of the scattered light is directed down than up. However, the light scattered in a horizontal plane is practically the same as if the drop were remote from the ground, and it is this component of the scattered light which determines the horizontal visibility. (One of the great advantages of Koschmieder's treatment is that the particular angular distribution of the scattered light does not have to be known.)

The intensity of the light scattered by each cubic centimeter of fog is $2\pi na^2H$ where H is a measure of the uniform diffuse light within the cloud. A small cross-sectional element of the pyramid subtended by the object at the eye, of thickness dr, has a brightness of $2\pi na^2Hdr$. If the element is r cm. from the eye, its brightness at the eye is $2\pi na^2He^{-2\pi na^2r}dr$. The apparent brightness of the black object is the sum of the brightnesses of all of the elements in the pyramid subtended by the object.

$$B_0 = H\int_0^z 2\pi na^2e^{-2\pi na^2r}dr$$

where z is the distance from the object to the eye. Integrating,

$$B_0 = H(1 - e^{-2\pi na^2z})$$

The background brightness is given by the same integral with the limits 0 to ∞. Hence:

$$B_b = H$$

Presented at the Meteorology Session, Seventh Annual Meeting, I. Ae. S., January 26, 1939.

From Eq. (2) the limiting distance at which the object can just be seen may be readily determined, and

$$z = \log_e(1/\epsilon)/2\pi na^2 \qquad (3)$$

Comparison with Eq. (1) shows that ϵ corresponds to the transmission over a path equal to the visual range. Although ϵ is referred to as a constant, it is known to increase rapidly for low values of illumination or when the angle subtended by the object at the eye becomes less than about 2°.[3]

If w is the volume of water in the form of drops in a unit volume of fog,

$$w = (4/3)\pi na^3$$

By substitution in Eq. (3)

$$z = Ca/w \qquad (4)$$

where C is a constant. This is Trabert's formula for the visual range.[4]

In connection with measurements of the size and number of fog and cloud drops carried out for the past five years at Round Hill* and on the summit of Mt. Washington, a number of observations of the visual range and of the transmission of visible light over a measured path have been made. A complete discussion of the results of the measurements of the size and number of fog drops is beyond the scope of this paper and only typical or average figures will be considered.

The method used for the determination of the size of the drops involves the photomicrography of a representative sample of the drops which are deposited upon a suitably prepared slide.[5,6] The drop images are then measured individually. Typical photomicrographs of this type for fog and clouds are reproduced in Fig. 1. It will be seen that, in each case, there is a considerable range of sizes represented. Further, the range of sizes is greater for the fog than for the cloud, and the fog contains much larger drops than does the cloud. Typical size distribution curves which bring out these points graphically are given in Fig. 2. These curves show how the total water content is distributed among the various drop sizes.

* Round Hill is located on the west shore of Buzzards Bay about six miles south of New Bedford, Mass.

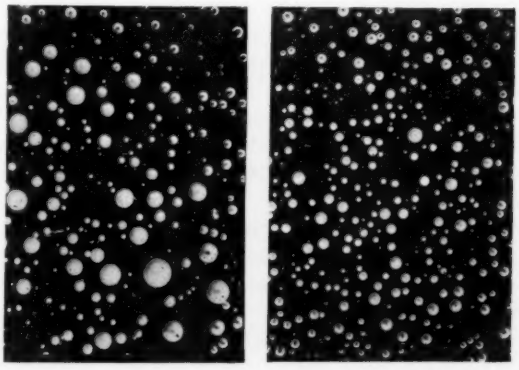

FIG. 1. Photomicrographs of fog drops (left) and cloud drops (right) taken at a magnification of about 50 x. The drops were caught on specially prepared slides and photographed in a special fog microscope.

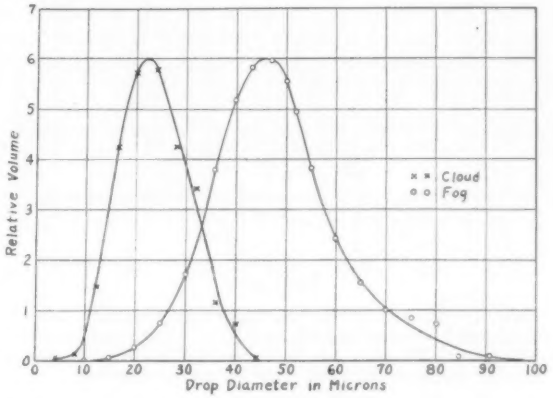

FIG. 2. Typical drop size distribution curves for a fog and for a cloud. The curves are plotted so as to show how the liquid water is distributed amongst the various drop sizes.

The number of drops in a unit volume of air was arrived at by measuring the liquid water content of a unit volume of air[6] and then applying the observed drop size distribution. The liquid water contents in fog were found to range from 0.05 to 0.25 gm. per cu. meter. Clouds were found to be much wetter, with liquid water contents ranging from 0.5 to 1.5 gms. per cu. meter, and higher values probably often occur. The larger amounts of liquid water found in clouds together with the smaller average drop size shows that clouds contain many more drops per unit volume than does fog. It was found that there were from 50 to 500 drops per cc. in clouds and only from 1 to 10 drops per cc. in fog.

Since these measurements definitely show that a considerable range of drop sizes is present in a fog or cloud at any instant, the term na^2 in Eqs. (1) and (3) must be replaced by Σna^2 where the summation is to include each size group to which the various drop sizes have been assigned. The a in Eq. (4) must then be an average drop radius defined by $\Sigma na^3/\Sigma na^2$. The average diameter is approximately equal to the abscissa corresponding to the maximum of the drop size distribution curve.

Although a great deal of the data obtained at Round Hill were taken at night, there were a number of occasions on which simultaneous observations of the daytime visibility and of the transmission of visible light were made. By means of Eqs. (1) and (3) it was then possible to determine the value of ϵ. It was found that ϵ ranged from 0.016 to 0.060, with an average value of about 0.03, or about twice the accepted value.

During some fogs a nearly continuous record of visibility and liquid water content, w, was obtained.

Typical results are given in Fig. 3, which is taken from a paper by W. H. Radford,[6] an associate of the author's in this work. A general inverse relationship between the visibility and the liquid water content, in accordance with Eq. (4), is apparent. If the liquid water content

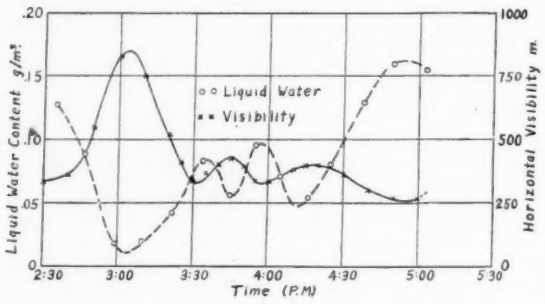

FIG. 3. Curves showing the liquid water content and the estimated horizontal daytime visibility as a function of time for a Round Hill fog. A general inverse relationship between the visibility and the liquid water content is apparent.

is plotted against the visibility on log paper, it is found that the slope is about 0.6 instead of 1.0 as would be expected from Eq. (4) if a were constant. If it is assumed that the number of fog particles remains constant rather than the size, a becomes proportional to $w^{1/3}$ and Eq. (4) may be written

$$z = C'/w^{2/3}$$

This is evidently more nearly in accordance with the observed average exponent of 0.6. Since the exponent varies over a considerable range (0.4 to 0.8) there is no absolutely fixed relation between the visibility and the liquid water content.

Unfortunately the data on clouds suffer from instrumental difficulties due to the rather severe weather conditions encountered on a mountain top. In particular it has been found that the density of the clouds changes with such rapidity that the inherent lag of some of the apparatus becomes an important factor. For the same reason the visibility changes very rapidly and is usually not the same in different directions. In spite of these difficulties some interesting results have been obtained.

The visual range in a cloud is much shorter than that in most fogs and probably averages about 50 meters as compared to about 300 meters for fogs of the type encountered at Round Hill.

A series of about thirty simultaneous observations of the visibility and of the transmission of visible light permitted a fairly accurate estimate to be made of the value of ϵ for clouds. The average is 0.065, or about twice the value found for Round Hill fogs, which, in turn, is about twice the value usually found from laboratory experiments. There is no evidence that the general illumination was low enough to account for such an increase in ϵ, and it is possible that it is due to what Bennett[7] has called the "ground glass plate effect." The "fuzzy" appearance of the edges of objects viewed through a fog is a manifestation of this effect. The object and the background are thus separated by a diffuse boundary rather than by a sharp line such as is usual in laboratory determinations of ϵ. This question has recently been investigated in the laboratory by Middleton.[8] He found that there was little change in ϵ until the angular extent of the diffuse boundary exceeded about 5 minutes of arc. From this point ϵ increased linearly with the angular extent of the diffuse boundary. From his results it appears that the diffuse boundary would have to subtend at least 15 minutes of arc to explain the observed value of ϵ of 0.065. It seems doubtful that the diffuse boundary could be this wide in fog.

Because of the extremely rapid fluctuations in the liquid water content in clouds the inverse relationship between visibility and the liquid water content is not brought out clearly by a curve of the type presented in Fig. 3. However, when a considerable number of simultaneous observations of visibility and liquid water content were plotted against each other on log paper, it was found that the two were very nearly inversely proportional. From Eq. (4) this means that the average particle radius a tends to be constant in clouds although here again this is only an average result and the deviations from it in individual cases are considerable. It will be recalled that in the case of fog, it was found that the number of drops per unit volume tended to remain constant.

This point was investigated further by means of the drop size distribution data. For each set of drop size data the value of Σna^2 for one gram of liquid water per cubic meter of air was computed. If this value of the summation is called S, Eq. (3) may be written

$$z = C''/wS$$

where C'' is a constant and w is the liquid water content of the cloud in gms. per cu. meter. It was found that the value of S was surprisingly constant, the total range being about 3:1 for all of the clouds on which data were available. The range was much narrower for individual series of observations and S often remained constant within the precision of measurement. This result is in agreement with the apparent inverse relationship between visibility and the liquid water content. It is interesting to note that the value of S is always higher for "dry" clouds than for misting or raining clouds. The average value of S for "dry" clouds is about 0.25×10^{-3} and is about 0.12×10^{-3} for "wet" clouds. In other words, the visibility is about twice as great in a "wet" cloud as in a "dry" cloud of the same liquid water content. However the liquid water content of a "wet" cloud is usually considerably greater than that of a "dry" cloud.

Since the results given in this paper are based on a very small amount of data, it is possible that the tentative conclusions reached will be considerably modified

when more complete data are available. It is planned to continue the observations of visibility and related quantities in connection with a comprehensive investigation of the condensation and precipitation processes in the atmosphere. Similar information may be obtained for the visibility of lights at night through fog and clouds.

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Book Reviews

Metals, by Sir Harold Carpenter and J. M. Robertson; Oxford University Press, London, 1938; 1447 pages, $35.00.

This is no ordinary book; it is a library, an encyclopedia, and a course in physical metallurgy. In the preface a promise is made.

"The general object of this book is to describe the characteristics of metals and explain how they are related to composition and treatment on the one hand, and properties on the other. The characteristics of a sample of metal comprise its composition, constitution, microstructure, crystal structure, and condition, and we have endeavored to describe each of these separately and to trace the relations between them. Finally, we have tried to explain how composition and treatment influence the characteristics, and how these in turn influence the mechanical, chemical, electrical, magnetic, antifrictional, and other properties. With this general object in view there are several alternative ways in which the subject matter could be presented, and a considerable amount of attention has been given to the arrangement of this book in order to make it possible for any one with some scientific or mechanical training, but without any previous knowledge about metals, to begin at the beginning and build up a moderately comprehensive knowledge of the subject as he reads."

Those who read this book will find themselves with much more than a "moderate" comprehension of the art and science of metals. A reader will become a student and pursue his particular interest into the 585 references. It is not often that a technical work can so present the subject as to entice further search, beyond the immediate need of the moment, but this book demands to be read and studied throughout.

The contents are divided into six parts. Part 1 covers microstructure, crystal structure, time, temperature, deformation, and fracture; part 2, constitution and structure of alloys; part 3, strength properties of metals including the effects of time and temperature and a 110 page chapter on oxidation and corrosion, constituting in itself a notable volume; part 4, the treatment of metals, including casting, heat and mechanical treatment; part 5, industrial ferrous alloys; and part 6, non-ferrous metals and alloys. In every case the practical importance of the mechanical properties; strength, in all its manifestations of hardness, wear resistance, corrosion resistance, reaction to temperature, impact, and repeated load, is most carefully considered, together with the present-day knowledge of composition, heat treatment, and structure on these engineering properties. In all of these complicated relationships the specialists will find references to the most important technical articles covering the points in question.

For the engineer, this volume will act as an encyclopedia and guide to facts in the vast and bewildering periodic literature; saving much time normally lost on "rehash" articles. But the facts are different from those of a handbook, even the glorified handbook of the American Society for Metals, in that the reasons for the facts are so satisfactorily set forth.

The book will explain engineering strength of metals to the metallurgist and the most advanced metallurgy to the engineer. Every technical man should have it, every student should read it.

A. V. de Forest
Massachusetts Institute of Technology

Elements of Practical Aerodynamics, by Bradley Jones; John Wiley & Sons, Second Edition, 1939; 402 pages, $3.75.

The first edition of this book, which appeared in 1936, has been widely used as a college text in beginning courses in aeronautics. The new material appearing for the first time in this second edition includes a description of N.A.C.A. airfoils, the standard taper of a monoplane wing, the graphical method of developing a streamline contour, a mathematical treatment of range and take-off distance, and an abridgement of Oswald's method of rapid prediction of performance. In various parts throughout the book, especially in the chapter on longitudinal balance, the treatment of the subject has been enlarged for purposes of clarity.

The subject matter is clearly and logically presented in most respects. However, it would seem that the forces on bodies should be explained by reference to the flow about them rather than with recourse to the concept of impinging particles.

In the chapter on "Auxiliary Lift Devices," Fig. 88b, entitled "Effect on lift coefficient of slots and flaps" gives the incorrect impression that the lift curve versus geometric angle of attack for slotted and flapped wings are identical at small angles with that for the wing alone. Inasmuch as no ordinates or abscissae are designated, this impression seems unavoidable.

Considering the book as a whole, it gives the student aeronautical engineer a good foundation for more detailed courses in most of the various subjects. Of particular merit is the large number of practical problems based on the subject matter of the various chapters.

Sound and Pressure Waves in Detonation

C. E. GRINSTEAD

General Motors Research Division

SUMMARY

This paper presents studies of the relationship between the frequency of pressure waves in the combustion chamber and the audible sound in air produced by detonation. Three engines have been investigated: a Diesel, an overhead-valve spark-ignition, and an "L" head spark-ignition engine. Sound and pressure waves picked up with a microphone and carbon-stack indicator, respectively, were recorded simultaneously by photographing the screens of two cathode ray oscillographs. Some of the records are reproduced in this paper, and it is shown that there is a one-to-one correspondence between the frequency of the shock waves in the combustion chamber and the frequency of the audible sound in air. Other interesting features of the records are discussed.

INTRODUCTION

EVIDENCE that shock waves existed in the combustion chamber of internal combustion engines was first obtained in the General Motors Research Laboratory in 1930. In taking time-displacement photographs of the flame under violent detonating conditions, visible waves in the luminous gases indicated that a pressure wave was traveling back and forth across the combustion chamber. Apparently the temperature changes resulting from the compression and expansion processes within the wave were of sufficient magnitude to cause large variations in the luminosity of the burned gases.[1] From the velocity of the pressure wave in the gases, an estimate could be made of the average temperature in the combustion chamber.

Early in 1933, Wawriziniok[2] presented evidence showing that the frequency of the superimposed vibrations on the pressure indicator cards from a combustion bomb was the same as the frequency of the audible sound. One pair of sound and pressure records from a gasoline engine was also recorded. In describing the latter, it is stated that the frequency of the superimposed pressure vibrations in this case was also the same as the frequency of the audible sound, but the reproduction of the record was not suitable for a study of this relationship.

In 1934, Taylor, Draper, Taylor, and Williams[3] advanced the theory that "resonant pressure or sound waves in the combustion chamber" are responsible for the shock waves shown on time-displacement flame photographs of detonating explosions. These shock waves in turn set up forced vibrations of the same frequency in the cylinder walls. The latter are responsible for the characteristic sounds of detonation. In presenting a mathematical analysis of this theory, Draper[4] states, however, "sound records were taken with a condenser microphone placed in free air near the engine" and that "sound frequencies recorded by an external microphone are the same as those shown by the indicator in contact with the cylinder gases." Photographic records were not presented in either of these papers to show the nature of the relationship between the frequencies of the shock waves and audible sound.

The first photographic evidence of a definite relationship between the shock waves in the combustion chamber and the pressure vibrations superimposed on the expansion portion of the indicator card was published in 1934.[5] In this paper records were presented which showed a one-to-one correspondence between the frequency of the waves in the luminous gases of the combustion chamber and the superimposed pressure vibrations on the indicator record.

Further evidence in favor of the theory of a resonant-pressure wave in the combustion chamber was presented in 1937 by Boerloge, Broeze, van Driel and Peletier.[7] These investigators showed that the amplitude of the superimposed vibrations obtained on the pressure records varied with indicator location in the combustion chamber. The maximum and minimum pressure changes were recorded near the end and center of the combustion chamber, respectively. These points would correspond to the nodes of a resonant sound wave, if such a wave existed in the combustion chamber.

In contrast to the above evidence which indicates that the frequency of the sound of detonation may be the same as the frequency of the shock waves in the combustion chamber, Dodds[6] concluded (on the basis of a study of a series of pressure and sound records of detonating engine explosions):

(1) That the sound of detonation is due to the ring of the metal cylinder when struck internally by a steep pressure rise.

(2) That the waves in the gases do not involve anywhere near the same frequency as those of the audible sound.

In a survey of the literature, records could not be found which were suitable for a study of the relationship between the audible sound in air and the pressure waves in the combustion chamber. Since it was desirable to study the relationship, a series of indicator

Presented at the Power Plants Session, Seventh Annual Meeting, I. Ae. S., January 26, 1939.

and sound records were taken on three internal combustion engines.

Apparatus

Three internal combustion engines of widely different design were used, namely: a General Motors Research $5^1/_2 \times 5^3/_4$ in. single cylinder, two-stroke cycle, overhead valve, Diesel test engine; a modified Delco $2^5/_{16} \times 2^9/_{16}$ in. single cylinder, four-stroke cycle, "L" head gasoline engine; and a $3^1/_4 \times 4^1/_2$ in. single cylinder, variable compression, four-stroke cycle, knock testing, gasoline engine.

A Shure type 70-H crystal microphone was used for recording the audible sound. The microphone was suspended freely in air at all times.

A new type single carbon-stack pressure indicator was used for obtaining all the pressure records presented. A cross-sectional view and photograph of the indicator are shown in Fig. 1. The indicator is mounted

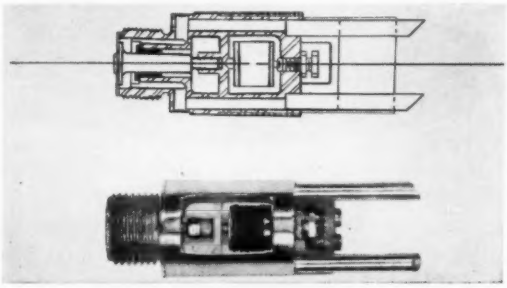

Fig. 1. Pressure indicator.

in the engine head with the diaphragm flush with the wall of the combustion space. The temperature effect produced by combustion is reduced by using a thin water cooled diaphragm. The diaphragm is connected by means of a light push rod to a heavy cross beam which is made as an integral part of the indicator by machining the entire frame from a single piece of invar metal. This cross beam is used to introduce the stiffness component of the spring system necessary to produce a high natural frequency of vibration. The cross beam is made with a stiffness such that the displacement of the beam is 0.0005 in. for the maximum pressure to be applied to the diaphragm of the indicator.

The pressure sensitive element consists of a stack of thirteen hard carbon discs approximately $^7/_{16}$ in. O.D., $^{13}/_{64}$ in. I.D., and $^1/_{64}$ inch thick, mounted in the indicator frame as shown in Fig. 1. The stacks are first given an initial pre-load of approximately 25 pounds and then heat treated for five minutes at a dull red temperature in nitrogen. The high temperature apparently removes foreign matter from the discs and increases the sensitivity of the stack. The pre-load is then re-adjusted to give a stack resistance of 12 ohms. A detailed description of the carbon-stack for indicator use had been presented elsewhere.[8]

An electric current of 100 milliamperes was initially passed through the stack, and the voltage drop due to the resistance of the stack was used to furnish a negative bias voltage for the grid of the first vacuum tube in an electronic voltage amplifier.

Any variation in the pressure on the diaphragm which is exposed to the combustion chamber results in a change of pressure on the carbon-stack. Since the carbon-stack is a semi-conductor, a change in pressure alters the stack resistance, which, in turn, varies the bias voltage applied to the grid of the first amplifying tube.

The amplifiers for both the crystal microphone and the carbon-stack indicator consisted of three stage resistance-capacitive circuits which had frequency responses that were linear from 2 to 10,000 cycles per sec. The output from the amplifiers was fed directly to the horizontal deflecting plates of RCA type 908 cathode ray tubes, see Fig. 2. These tubes have a fluorescent

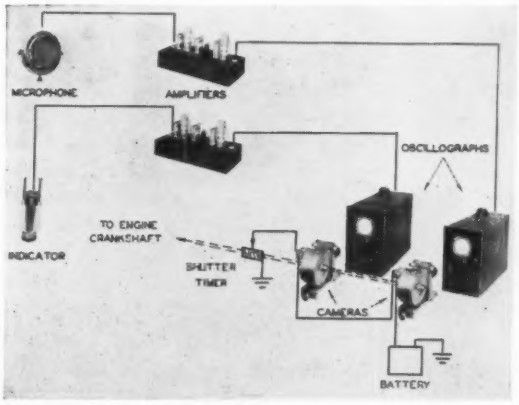

Fig. 2. Recording equipment.

coating known as phosphor 5 which has the desirable characteristics of a very short time of spot persistence, and a trace that is highly actinic.

A pictorial sketch of the recording apparatus is shown in Fig. 2. The cameras consist of a revolving drum on which is mounted a 12.25 in. strip of 35 mm. film. The drum mounts in a housing that is equipped with an electromagnetic shutter and a Hugo Meyers F:1.5 lens of 2 in. focal length. The camera drums move the film in a direction that is at right angles to the displacement of the cathode ray spot, which in one case is proportional to the pressures in the combustion chamber, and in the other case proportional to the pressure of the sound waves in air. This type of moving film camera was chosen because it gives a linear time axis without involving the inherent difficulties that would be encountered by trying to use sweep circuits on the cathode ray oscillographs.

Two cameras were used because it was necessary to photograph simultaneously, both the high pressure indicator and sound records. The two cameras were

connected together and driven directly from the engine crankshaft, see Fig. 2. Since the speed of the camera drums was the same as the speed of the engine crankshaft, it was easy to calculate the velocity of the revolving film and determine the recorded frequencies.

Data

When the equipment was first put into operation, a visual study was made of the pressure records in the combustion chamber and the sound records. It was noted immediately that when the engine began detonating, two very distinct changes took place on the records. The first change consisted in the appearance of a pressure vibration of relatively high frequency superimposed on the expansion portion of the pressure-time card, and the second change was the appearance of a new wave component of considerable magnitude and relatively high frequency superimposed on the sound record.

The microphone was located in several different positions in order to find the point of greatest sound intensity. On the Diesel engine, the microphone was first located near the engine crankshaft, and a very predominate sound was obtained in the range of 600 cycles per sec. This sound wave was always present to a certain extent even when the engine was not detonating. The microphone was then located very near the engine head, and even though the 600 cycle sound wave was still predominate, it was possible to detect a higher frequency component that appeared only when the engine was detonating.

A composite photographic sound and pressure record taken on the Diesel engine under non-detonating conditions is shown in Fig. 3. The upper trace is a pressure-time card taken inside the combustion chamber by means of the carbon-stack pressure indicator, while the lower trace is a sound record taken in air near the engine head. Pressure reads from bottom to top on the upper trace; time reads from left to right. The sequence of events on the high pressure cards are as follows: from A to B, compression; at point C, ignition; at point D, maximum pressure; and from D to E, expansion. The corresponding sound record for the same engine cycle is shown in the lower trace.

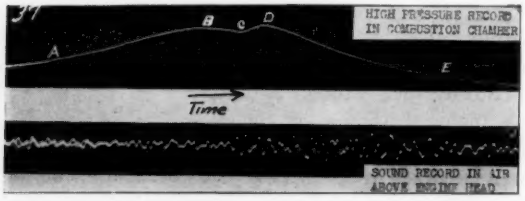

Fig. 3. High pressure indicator and sound records of combustion in a Diesel engine. Speed, 600 r.p.m.; fuel, high speed Shell No. 3; end of injection, 2° B.T.C.; throttle, 1/3 open.

Fig. 4 shows a composite record for the Diesel engine under detonating conditions. The load remained the same as before, but injection timing was advanced five degrees. The sequence of events on the high pressure records is the same as for non-detonating combustion, with the exception of the appearance of pressure vibrations in the form of a superimposed wave on the expansion portion of the records. On the corresponding sound record, the effect of detonation produced the superimposed high frequency wave shown in the lower trace of Fig. 4.

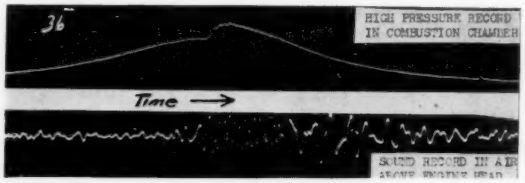

Fig. 4. High pressure indicator and sound records of combustion in a Diesel engine. Speed, 600 r.p.m.; fuel, high speed Shell No. 3; end of injection, 7° B.T.C.; throttle, 1/3 open.

In order to eliminate the possibility that the superimposed waves on the high pressure indicator cards were due either to vibration of the engine head, or to vibration of the indicator, itself, a visual study was made under detonating conditions with the indicator mounted in position but blanked off from the combustion chamber. It was not possible to detect any vibrations on the records with the blanked indicator.

Figs. 5 and 6 present pairs of pressure and sound records taken on the Diesel engine with the injector timing advanced to 7 degrees before top dead center to produce detonating combustion. It is shown by the alignment of the composite photographic records that a one-to-one correspondence exists between the frequency of the superimposed pressure waves on the indicator record and the frequency of the corresponding sound waves.

The ends of the film on the camera drums were very carefully aligned by means of fixed points before the cameras were connected to the engine crankshaft, and thus the pressure indicator and sound records could be compared in their correct time relationships.

Since the microphone was located approximately 1/2 inch from the engine head, the time of travel of the sound from the combustion space to the microphone was very small, consequently the pressure and sound records are slightly out of phase, but the extent of this is too small to be noticeable in Fig. 6.

The frequency of the superimposed pressure waves decreases a small amount (approximately 5 to 10 percent) as the gases in the combustion chamber expand. This is probably due to the decrease in temperature of the gases. All of the frequencies given in this paper refer to the highest frequency portion of each record.

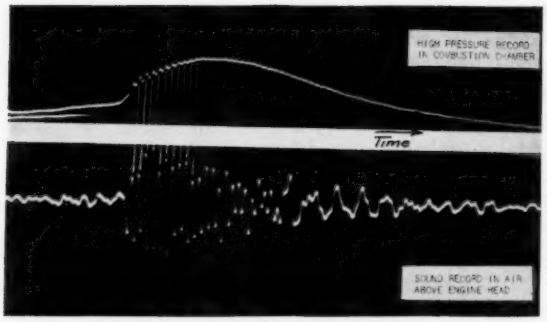

FIG. 5. High pressure indicator and sound record of detonating combustion in a Diesel engine (composite enlargement). Speed, 600 r.p.m.; fuel, high speed Shell No. 3; end of injection, 7° B.T.C.; detonation frequency, 3390 cycles per sec.; sound frequency in air, 3390 cycles per sec.; throttle, full.

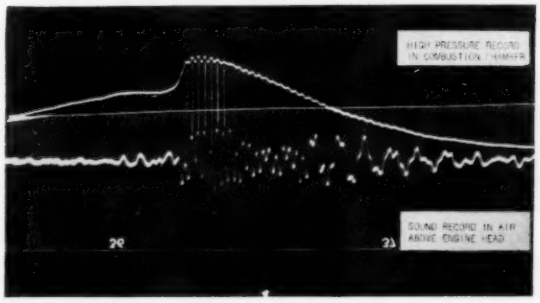

FIG. 6. High pressure indicator and sound record of detonating combustion in a Diesel engine (composite enlargement). Speed, 600 r.p.m.; fuel, high speed Shell No. 3; end of injection, 7° B.T.C.; detonation frequency 3550 cycles per sec.; sound frequency 3550 cycles per sec.; throttle, $^1/_2$ open.

It is apparent from the records that the duration of the audible sound of detonation is approximately equal to the duration of the pressure waves in the combustion chamber, as evidenced by the indicator card. It should also be noted that the general noise level is higher after the occurrence of the sound waves due to detonation than before. This is probably due to free vibrations set up in some of the engine parts.

In Fig. 6 an unusual effect in the pressure variations on the indicator record is noted. This effect was noted visually on several records of the Diesel engine. There is a tendency for the pressure waves to disappear and reappear in a more or less systematic manner every four or five cycles of the wave. The data obtained are not sufficient to satisfactorily explain the phenomena, although a possible cause of the effect is that a type of beat may be produced by two shock waves of slightly different frequencies traveling through the gas medium. The existence of two waves traveling at different velocities in the combustion chamber has been proposed by A. Sokolik and A. Voinov.[9]

Delco Engine

The recording equipment was also used on a modified Delco gasoline engine. This engine was of the L head type and had a combustion chamber length of approximately $5^1/_2$ inches.

On the basis of the observations with the Diesel engine, one might expect the greatest sound intensity to be found near the engine head. But as it was shown by preliminary experiments, the intensity of the sound of detonation was minimum near the engine head and maximum near the engine flywheel.

An enlarged composite photographic sound and pressure record taken with the Delco engine under detonating conditions is shown in Fig. 7.

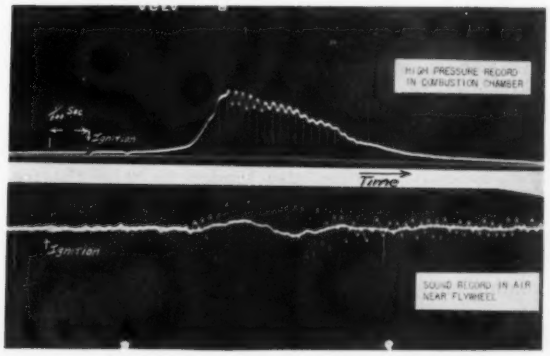

FIG. 7. High pressure indicator and sound record of detonating combustion in a gasoline engine (composite enlargement). Speed, 700 r.p.m.; fuel, A-4 Reference gasoline + oxygen; spark advance, 25°; detonation frequency, 3330 cycles per sec.; sound frequency in air, 3330 cycles per sec.

In aligning the records from the Delco engine, the time axis of the sound record was shifted to the left by an amount which was equivalent to approximately $^1/_{600}$ of a second (see Fig. 7). This shift facilitates the comparison between the frequency of the pressure waves on the indicator card and the frequency of the sound record. The exact amount of this shift could not be accurately determined because the time of travel of the sound to the microphone is not definitely known. The time axis of the sound record can be shifted several cycles of the wave without affecting the correspondence. Therefore, in the alignment shown it cannot be stated that the pressure waves on the indicator cards are aligned with exactly corresponding sound waves, but the one-to-one correspondence of the frequencies in the two records can scarcely be doubted. The records in these figures show a one-to-one correspondence between the frequencies of the pressure waves on the indicator card and the audible sound.

Several records were taken at different speeds and with various fuels in the Delco gasoline engine, and in every case there was a one-to-one correspondence between the frequencies of the pressure waves and the corresponding audible sound. The average frequency of the pressure and sound waves from five records using cleaners naptha as a fuel was 3120 cycles per sec. Four records using third grade gasoline gave an average frequency of 3190 cycles per sec.

If the audible sound of knock were caused by forced vibrations, it seemed logical that if the frequency of the shock waves were increased or decreased, there should be a corresponding increase or decrease in the sound frequency. One convenient way of changing the frequency of the shock waves is by the addition of oxygen, which raises the temperature of the gases in the combustion chamber, and hence the frequency of the shock waves.

The average frequency obtained from three records using naptha and oxygen was 3415 cycles per sec.; and the frequency from eight records using A-4 reference fuel and oxygen was 3320 cycles per sec. These values compare with frequencies from 3100 to 3200 cycles per sec. when operating without added oxygen. In other words, the addition of a small amount of oxygen to the fuel-air mixture raised the frequency approximately 10 percent. The addition of a knock inducer, iso-amyl nitrate, also tended to raise the frequency of the pressure waves. It was found that regardless of the change in the frequency of the pressure waves in the combustion chamber, there was a corresponding change in the sound frequency.

Records were taken at various speeds in order to see if the frequency of the sound was altered by a change in engine speed. No appreciable change or definite trend in the frequency of the pressure and sound waves could be attributed to a change in engine speed.

Knock Testing Engine

The recording equipment was next set up on an overhead valve gasoline engine. Here, the length of the combustion chamber was small. The engine chosen was the G.M.R. variable compression, knock testing engine. This engine has a bore of $3^1/_4$ inch.

A record taken on this engine is shown in Fig. 8. Here, again there is a one-to-one correspondence between the frequency of the pressure and sound waves. The frequency of the waves obtained is approximately 5900 cycles per sec.

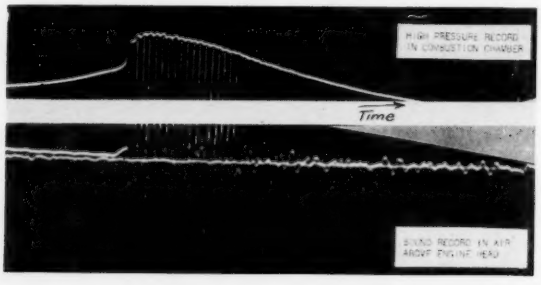

FIG. 8. High pressure indicator and sound record of detonating combustion in a gasoline engine (composite enlargement). Engine speed, 1000 r.p.m.; fuel, Standard gasoline; spark advance, 30°; detonation frequency, 5900 cycles per sec.; sound frequency in air, 5900 cycles per sec.

By listening to this engine under detonating conditions, it was immediately ascertained that there were two predominate frequencies in the sound from the engine. Several records were taken with the microphone located near the engine crankshaft. These records show that the lower predominant frequency of the noise is approximately 3090 cycles per sec. This sound is probably caused by some vibrating mechanical part set in motion by the high rate of pressure rise in the combustion chamber.

A record was taken when the engine was operating as a compression-ignition engine (see Fig. 9). A compression ratio of 12:1 and N-pentane fuel were used in order to obtain this condition. There is little or no detonation indicated by the pressure record, but the audible sound was very pronounced. This audible sound was in approximately the same frequency range (3090) as the low frequency component of sound obtained under detonating conditions.

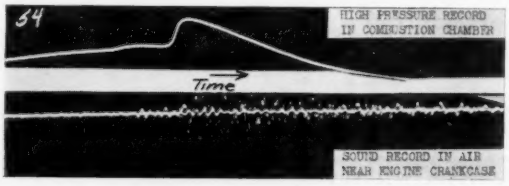

FIG. 9. High pressure indicator and sound records of combustion in a gasoline engine. Engine speed, 610 r.p.m.; fuel, Normal Pentane (self ignition); compression ratio, 12:1.

It is interesting to note that in the case of both the overhead valve engines, a predominate low frequency component is present in addition to the frequency of detonation, whereas in the L head engine only the frequency of detonation is present.

If the theory of sound is the correct interpretation of the shock waves in the combustion chamber, another interesting comparison can be drawn between the overhead valve engine and the L head engine. The combustion space in overhead valve engines is usually confined to a cylindrical volume above the engine piston while in L engines the combustion includes the volume space above the engine piston plus the added volume above the valves.

The pressure of the shock waves on this account in an L head engine will be successively maximum and minimum over the piston and the force transmitted by the piston to the connecting rod due to the shock waves will likewise be successively maximum and minimum; whereas in the overhead valve engine the pressure over the piston will be simultaneously maximum and minimum and the resultant total force transmitted by the piston to the connecting rod due to the shock waves will be zero, this indicates that the shock wave in an L head engine may have the most tendency to force the crankshaft to vibrate at the shock wave frequency. This may also account for the differences in the audible sound of detonation between different types of engines.

Conclusions

In a study of the photographic records and data obtained from three internal combustion engines the following conclusions were made:

(1) A one-to-one correspondence exists between the frequency of the shock waves in the combustion chamber and the frequency of the audible sound in air.

(2) A predominate low frequency wave component was present in the sound from the high compression overhead valve engines, in addition to the high frequency wave component due to detonation.

(3) The duration of the audible sound of detonation approximates the duration of the pressure waves in the combustion chamber as evidenced by the indicator cards.

(4) The audible sound of detonation was most perceptible near the engine head in the overhead valve engines. In the L head engine the sound of detonation was most perceptible near the engine flywheel.

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Book Reviews

Unsolved Mysteries of the Arctic, by Vilhjalmur Stefansson; The MacMillan Company, New York, 1939; 369 pages, $3.50.

When a distinguished member of the Institute writes a book which covers a field closely allied to aviation, such as exploration, and in it gives his opinion, based on long personal experience and observation, of the possibilities and practicability of flying in the Arctic, it will doubtless be eagerly read by many members who wish relaxation from the "must" list of aeronautical publications.

Mr. Stefansson has for many years been the leading proponent of the practicability of flying in the Polar regions. His advice and suggestions have been sought by many who have explored the great northern area. As President of the Explorer's Club he has been a leader of all kinds of exploration but he has never failed to expound the advantages of the airplane as a vehicle for Polar expeditions.

In this book he devotes two of the five chapters to famous flights; one concerns the Andrée balloon attempt to fly over the North Pole, and the other deals with the disappearance of the Soviet pilot Levanevsky. However, no one who starts to read the fascinating stories of the disappearance of early colonists in Greenland, the tragic fate of Sir John Franklin, and the speculation on the fate of Thomas Simpson in Northern Canada, will skip many pages to get to the part of the book dealing with aviation. Stephen Leacock writes in his Introduction, "Arctic exploration, insofar as it can be carried out from an arm chair before a winter fire, has long been for me a pursuit that verges on passion." This book may induce others also to use this field of reading as a mental stimulant.

The chapter on Andrée reviews all of the available data on the flight and gives a hypothetical analysis of what probably happened during the flight and how the members of the party died as the result of poisoning from the fumes of a primus stove. The reconstruction of this mystery can now be documented, so that conclusions may be reached, taking this great effort out of the list of unsolved mysteries.

Of greater immediate interest is the author's account of the Soviet flight in 1937, the year in which two other Russian flights were so successful. So little is known of what happened to Levanevsky that a wide field is opened for guessing as to his fate. The search by Sir Hubert Wilkins and others on this side of the Pole and by the Soviet pilots on the other side is described in a way that makes a conclusive case for the practicability of Arctic flying. Mr. Stefansson believes that hope of the reappearance of some of the party should not be abandoned for four or five years. He injects interesting comments on the resulting good will that often comes from the cooperation of countries after accidents of this kind. The great service rendered by the United States and the facilities which were made available for the search undoubtedly did much to enhance the friendly relations between the U.S.S.R. and this country.

Lester D. Gardner

Model Aeroplanes, by M. R. Knight; Percival Marshall & Co., Ltd., London; 101 pages; 1 s.

Condensed into comparatively few pages of this book is all a boy needs to know about the theory of flight to allow him to build his models with an adequate understanding of the principles involved. The model builder is given a simple explanation of the problems of design and stability so that when he completes his construction he will have a miniature flying machine which embodies some of his own ideas as well as those on the blue prints. Captain Geoffrey de Havilland, in the Foreword, writes: "You may, without knowing much about principles of design, build a model which flies well, but that is the result of luck and not of judgment."

Effect of Shear Lag upon Wing Strength

H. W. SIBERT
University of Cincinnati

SUMMARY

Experimental and theoretical evidence is drawn upon to show that, due to shear lag, and airplane wing with longitudinal stringers should be less efficient from a strength-weight standpoint than a wing which does not have longitudinal stringers in addition to the main wing beams.

INTRODUCTION

WHEN semi-monocoque construction was first employed on airplane wings, designers believed that each plane cross-section of the wing would remain plane after bending, which would cause the stress at any point of a wing structure, including the skin, to be proportional to its distance from the principal axis about which bending occurs. Before long, though, it was realized that only a small part of the skin on the compression side of the wing, the effective width, could be considered to have the same stress as the stringer or flange adjacent to it. With this refinement, the stresses in semi-monocoque wings were thought to obey the ordinary beam formula, $s = My/I$. Believing this to be true, designers could see a decided structural advantage in distributing the tension and compression flanges of the wing beams across the chord in the form of logitudinal stiffeners. Such stiffeners, apparently, would be just as effective in contributing to the bending strength of the beam as if they were an integral part of the flange of a wing beam. In addition, they would help materially to brace the metal skin and so prevent any great change in the aerodynamic shape of the wing sections under load.

EFFECT OF SHEAR LAG ON STRINGER STRESSES

Recent researches on "shear lag," particularly by Kuhn,[1] have demonstrated that the ordinary beam formula applies only to those portions of the wing which are an integral part of a true beam, *i.e.*, an upper and lower flange directly attached to a shear web, while the stringers receive their load only through shear deformation of the skin connecting it to the true wing beams. This phenomenon is known as "shear lag." The effect of shear lag is almost always to reduce the stress in a stringer below that given by the beam formula, $s = My/I$.

Due to shear lag, the employment of longitudinal stiffeners may result in a lowered weight-strength efficiency. Kuhn's experimental results[1] for a three-stringer beam with stringers in tension (Fig. 1) gave stresses of approximately 2800, 3200, and 6400 lbs. per sq.in. in the center stringer, intermediate stringer, and tension flange of the wing beam, respectively. Obviously, the metal in the stringers was not being used efficiently from a weight-strength standpoint, because the addition of one-half of the total stringer area to the flanges would contribute as much strength in bending at a flange stress of 6400 lbs. per sq. in. as the total stringer area would at the average stringer stress of 3000 lbs. per sq.in.

SKIN STRESSES

Actually, the analysis given above overestimates the reduction in wing efficiency somewhat because the effect of the stringers upon the tensile stresses in the skin was not considered. When stringers are on the tension side of a beam, as was the case in Beam No. 2, the skin should have at each point the same extension, and hence also the same stress, as the stringer or flange to which it is attached. Thus the skin of this beam carried a tensile stress which varied from 6400 to 3200 between the flange and the intermediate stringer and from 3200 to 2800 between the intermediate and center stringers. If the stress in the skin varied as a straight line in each portion of the skin, the average stress in the skin as a whole would be $(6400 + 3200 + 3200 + 2800)/4 = 3900$. But if the excess in skin stress from center to intermediate stringer and from intermediate stringer to flange varied as a parabola (Fig. 2), the average stress in these two portions of the skin would be, respectively, $2800 + (3200 - 2800)/3 = 2933$ and $3200 + (6400 - 3200)/3 = 4267$, or an average stress of 3600 for the entire skin. On the other hand, if all the stringers were made an integral part of the two tension flanges, the skin stress would vary from 6400 near the flange to zero at the center of the sheet, which would result in an average skin stress of $6400/2 = 3200$ or $6400/3 = 2133$, according as the skin stress varied as a straight line or as a parabola. But the combined

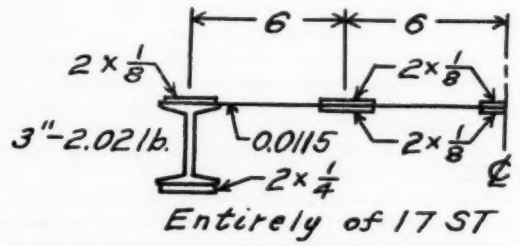

FIG. 1. Beam No. 2 of N.A.C.A. Technical Report No. 636.

Received April 5, 1939.

stringer area of this beam was 1.5 sq.in., while the area of the skin between flanges was 0.2415 sq.in. Hence, the incorporation of the stringers in the tension flanges would increase the load in the stringers by 1.5 (6400 − 3000) = 5100 pounds and decrease the load in the skin for a parabolic distribution of stress by 0.2415 (3600 − 2133) = 355 pounds, giving a net increase in strength of 4745 pounds.

The net increase in strength due to the incorporation of the stringers in the flanges of the wing beams would be larger for the compression side of the wing, because on that side the width of skin which may be considered to have the same compressive stress as the stringer adjacent to it would be only about 30 times the skin thickness. Hence the additional load carried by the skin adjacent to the stringers would be very small compared with the reduction of load in the stringers due to shear lag.

Additional Tests

Kuhn[2] also gives experimental results for a beam with flat tension side and only one stringer between the wing beams. At 7.5 inches from the wing root, the flange stress was 3260 lbs. per sq.in., while the stringer stress was only 1700. Here, again, the reduction of stringer stress due to shear lag is very large.

A considerable reduction in stringer stress on an actual airplane wing has been reported by the U.S. Army Air Corps.[3] This wing had six stringers between the wing beams on the lower side of the wing, and the experimental stresses in the central stringers were approximately 20 percent of the stress in the flange of the least stressed wing beam. However, part of this reduction in stress may have been due to a landing gear cut-out in the skin between the two central stringers. Hence, the designer should consider the possibility of an appreciable loss in weight efficiency in addition to that due to shear lag when stringers are used on the lower surface of a wing containing a landing gear cut-out.

Cambered Beams

The case in favor of incorporating all stringers in the flanges of the wing beams is not so clear cut for cambered as for beams with flat covers. Kuhn's test results[1] on a beam with cambered upper cover to which three stringers were attached (Fig. 3), showed stresses at the wing root of approximately 5000, 3500, and 4200 lbs. per sq.in. in the flange, intermediate stringer, and center stringer, respectively. It should be noted,

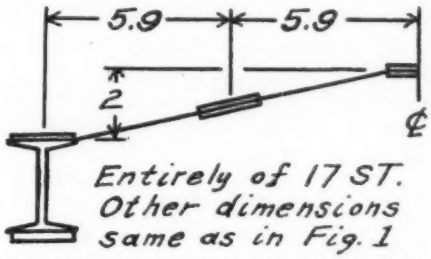

Fig. 3. Beam No. 3 of N.A.C.A. Technical Report No. 636.

though, that such large increases in stress in central stringers might not be realized in actual wing beams because Beam No. 3 has a much greater camber than would be found in most airplane wings; the center stringer was 2 inches above the top of the wing beams, which were 3 inches high and 23.6 inches apart.

Schapitz, Feller, and Koller[4] tested a cantilever wing with a more moderately cambered cover, the center stringer being 3 cm. below the bottom of the wing beams, which were 32.3 cm. deep and 110 cm. apart. This wing had seven stringers between the wing beams, and the stresses at the wing root were approximately 1110 and 620 in the flange and center stringer, respectively, when the beam had transverse loads at the free ends of the two wing beams. The stresses in the six intermediate stringers were all less than 620.

Even if the stringers near the deepest part of an airplane wing section have larger stresses than the stringers between them and the wing beams, the increase in wing efficiency due to their higher stress would generally be more than offset by greatly reduced stresses in the stringers which are closer to the center of gravity of the wing section than the flanges of the wing beams are.

Theoretical Formulas

The theoretical formulas developed by Kuhn in references (1) and (2) are partly empirical, but they check fairly closely the experimental results given in these two references. In a third paper Kuhn[5] gives calculated results for a cantilever beam with a flat cover, which show stress ratios varying from 1.21 to 1.91 when the beam had transverse loads at the free ends of the two wing beams. Kuhn defines the stress ratio as the ratio of the actual stress in the flange of a wing beam at the wing root to the corresponding stress calculated from the ordinary beam formula, $s = My/I$. Stress ratios greater than unity occur only when the stringers fail to take their calculated load, which obviously must cause an increase in the flange stress over that calculated from the ordinary beam formula.

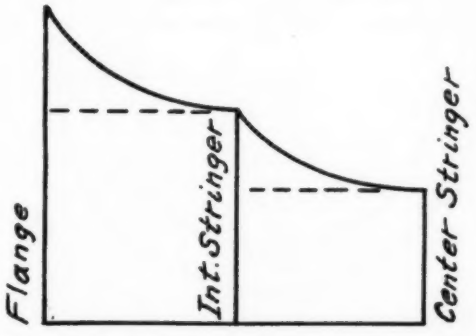

Fig. 2. Parabolic distribution of stress in skin.

E. Reissner[6] has developed a theoretical formula for a box beam with corrugated sheet cover and a single stringer between the two wing beams when loaded with transverse loads at the free ends of the wing beams. His Fig. 10 shows values of η, stringer stress at root divided by the corresponding flange stress, as low as 0.3 for a beam whose width is approximately equal to its length, and as low as 0.65 when the width is approximately half the length. In addition, his Fig. 10 shows that η decreases as the ratio of the stringer cross-sectional area to the skin cross-sectional area increases, which agrees with Kuhn.[5]

Conclusion

It would appear then that there is sufficient experimental and theoretical evidence available to make it probable that a design involving longitudinal stringers as part of the primary structure of an airplane wing is inefficient so far as bending strength of the wing is concerned. Hence, the use of longitudinal stringers can be justified only if they are needed to maintain a proper aerodynamic shape of the wing sections under load. But when used for such auxiliary purposes, their size should be kept as small as possible.

In addition to a probable reduction in wing efficiency from a strength-weight standpoint, the employment of longitudinal stringers as part of the primary structure may also reduce the wing efficiency from an aerodynamic standpoint. This is because the relatively high shearing stress in the skin between the wing-beam flanges and the adjacent stringers may cause diagonal wrinkles to form, such as those appearing in Fig. 18 of reference 1. At high speeds, such wrinkles, particularly when in the upper surface of the wing and near the leading edge, could not fail to increase the drag of the wing materially.

The conclusions reached in this paper are based on rather meager experimental and theoretical data, but that was unavoidable due to the lack of published reports of experimental stresses in stringers and wing-beam flanges. Tests of actual wings under load would demonstrate the undesirability of using longitudinal stringers as part of the primary structure.

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[5] Kuhn, Paul, *Bending Stresses in Box Beams as Influenced by Shear Deformation*, S.A.E. Journal, pages 319–324, August, 1938.

[6] Reissner, Eric, *On the Problem of Stress Distribution in Wide-Flanged Box-Beams*, Journal of the Aeronautical Sciences, June, 1938.

Personnel Opportunities

The Personnel Bureau serves individual members, as well as organizations seeking to employ aeronautical specialists. Any member or organization may have requirements listed without charge.

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Young man, single, studious, widely traveled, Army Reserve Officer, with $3\frac{1}{2}$ years mechanical drafting experience seeks new connection as draftsman with aircraft manufacturer. Reply Box 92, Institute of the Aeronautical Sciences.

The Airplane Brake

HENRY H. KERR AND F. C. FRANK

Bendix Aviation Corporation, Bendix Products Division

ABSTRACT

A criterion for brake design based on service experience with the conventional airplane is presented. This criterion relates the brake size with the gross weight and landing speed. Modifications for special operating requirements, such as the most severe taxiing conditions, are discussed.

The brake requirements for the tricycle geared airplane are discussed to show what modification of the criterion may be necessary when judging proper brake size. Variations in airplane usage are also shown to affect the size of brakes required.

INTRODUCTION

AIRPLANE brake design covers a wider scope than that for other vehicular brakes. This greater range is necessitated by weight limitation with resultant pressure on design details toward reductions of safety margins. The airplane brakes in addition to stopping the airplane are required to steer it while taxiing. Theoretically, steering requires only slight alternate application of brakes. Actually it requires considerable braking to offset the effect of cross winds which cannot be entirely corrected by the engines. When taxiing down wind the brakes may have to be used continuously to restrain the speed of the airplane.

Fig. 1 shows an internal expanding drum type brake showing the relationship between the rotating drum D and the fixed brake lining surfaces L. The fundamental relation governing the braking is $T = \mu F$, where T is the tangential force exerted by the lining on the drum, F is the radial force and μ is the coefficient of friction between the two surfaces.

Presented at the Air Transport Session, Seventh Annual Meeting, I. Ae. S., January 26, 1939.

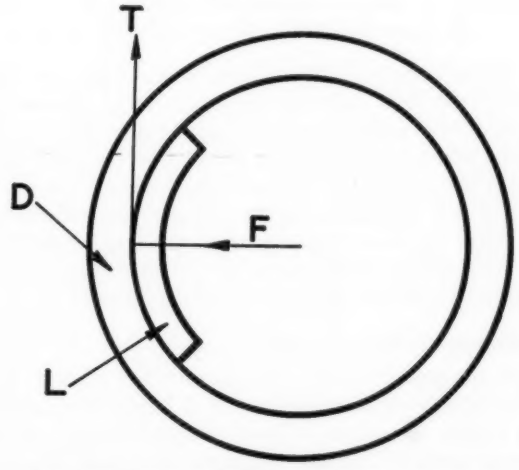


FIG. 1. Skeletonized internal expanding drum type brake. D, brake drum; L, lining; T, tangential force; F, radial force.

BRAKE LINING

The best brake linings will disintegrate at approximately 600°F. This disintegration, however, is gradual and sufficient warning is given to permit servicing prior to complete failure. Low heat conductivity is inherent to brake lining, therefore, it can dissipate only a negligible amount of the heat produced by the brake. The coefficient of friction between the drum and lining must be predictable at all temperatures. It is usually about 0.3 at low temperatures. As the temperature increases a proportionate decrease in the coefficient, known as "fade," is encountered. "Fade" necessitates increased application of the brakes by the pilot to maintain constant deceleration as the temperature rises.

BRAKE DRUM

The brake drum's purpose is threefold: (1) To provide a frictional surface on which the lining slides; (2) To resist the radial forces imposed upon it; (3) To handle most of the heat produced by the brake in deceleration and taxiing.

At high temperatures the material of the brake drum must be strong enough to withstand the loads imposed upon it by torque, the radial forces necessary to produce friction and the loads due to internal thermal stresses. Experience and a study of the characteristics of various materials indicate that ferrous alloys are best suited to meet these requirements.

The ability of the drum to dissipate heat limits the amount of work a brake and drum can do in a given time. The following example and its solution will demonstrate the magnitude of the heat produced during the landing run. To simplify the analysis it is assumed the flaps are not used in the landing run and the average propeller thrust is sufficient to offset the aerodynamic drag of the airplane. Thus, without introducing appreciable error the brakes are assumed to dissipate all the kinetic energy.

EXAMPLE OF BRAKING DURING LANDING

Heat Production and Flow

An airplane having a gross weight of 10,000 pounds and a normal landing speed of 80 m.p.h. comes to a

rolling stop at an average deceleration of 10 ft. per sec.^{2} The kinetic energy stored in the airplane at this landing speed is 2,125,000 ft. lbs. or 2731 B.t.u. The time required to stop the airplane is 11.7 seconds, thus heat is being generated in the brake drums and linings at the average rate of 233 B.t.u. per sec. The brake linings can absorb a negligible amount, therefore, it can be assumed that all the heat flows from the brake drum surface into the ring section of the drum nearest the lining. Fig. 2 shows a typical brake drum of diameter D. The shaded portion represents the ring section.

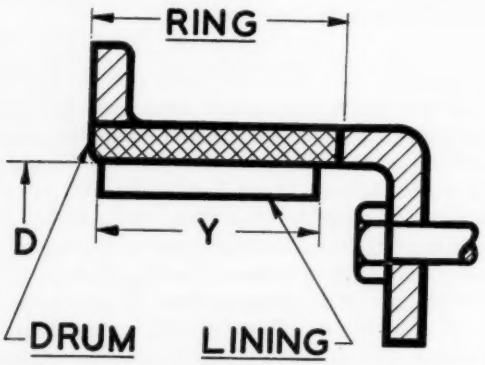


FIG. 2. Typical brake drum and ring. D, brake diameter; Y, brake width.

The rubbed drum surface area equals πDY. As soon as the temperature of the ring rises above its surroundings heat will flow from it. The heat will be radiated into the air and conducted to the rest of the drum, finally passing from the drum into the air and the contacting wheel portions.

The progress of the heat through the drum and away from it has been outlined. Unfortunately for the brake designer this is a gradual process and in the short interval of ten or eleven seconds the drum cannot be expected to dispose of much of its heat. The drum acts almost entirely as a heat reservoir and must be treated as such.

Consider the typical brake drum indicated in Fig. 2 as a heat reservoir assuming the allowable average temperature rise in the effective volume of the drum to be 750°F. The weight of the drum is derived from

$$\text{Wt.} = \frac{\text{B.t.u.}}{\text{Sp. ht.} \times N \times (T_1 - T_2)} \qquad (1)$$

Where N = number of brakes and $(T_1 - T_2)$ = average drum temperature rise. For the specific example Wt. = 15.5 lbs. per drum.

An average temperature rise of 750° is high, particularly when considering that the best grade of brake lining will disintegrate on its frictional surface at approximately 600°F.

Heat Stresses during First Second

A much worse condition exists during the first period of the brake application while the brake ring is still at atmospheric temperature and heat is being supplied to the brake surface at an average rate of 233 B.t.u. per sec. The result is almost instantaneous heating of a thin film of material at the surface. This surface reaches an exceedingly high temperature while the outer portions of the drum are still cool. Laboratory tests have been made to determine drum surface temperatures after one second of application under various unit heat loadings, where unit heat loading is 1 B. t. u. per sec. per sq.in. rubbed drum surface. As might be expected the temperatures vary almost in direct proportion to the unit heat loading. Further, the tests indicate this surface temperature after one second of brake application is usually higher than the average drum temperature after the complete landing run.

Assume the brake is applied so that 233 B.t.u. are generated in the first second. The unit heat loading versus surface temperature chart shows a drum area of approximately 250 sq. in. is required to limit the instantaneous surface temperature rise after one second, to 800°F. The use of two 14 × 3 in. brakes should provide the necessary drum area as their actual rubbed drum surface area is 264 sq.in.

Returning to the original assumption that during the first second a thin film is being heated, it is found that the thickness of this film to absorb 233 B.t.u. with an 800° temperature rise is $^1/_{32}$ in. Naturally, this thin film tries to expand, and if free to do so would increase approximately $^1/_4$ in. in its circumference. It is restrained, however, by the cooler outside surface thereby causing high thermal stresses within the drum. The braking surface is under high compressive stress while the outside is under high tensile stress. These stresses are approximately equal and may be computed from

$$\text{Stress} = CTEK \qquad (2)$$

Where C = coefficient of expansion of the material,
T = temperature differential,
E = modulus of elasticity, and
K = a constant for the material.

Stresses computed from the above formula are due entirely to heat and must be added to the stresses resulting from brake torque and radial load. For a given drum material the values of C and E in the above formula are also fixed; therefore, the stresses can be reduced only by decreasing the temperature differential between the inner and outer surfaces. The obvious way to do this is to reduce the unit heat loading at the surface to reasonable limits by increasing its area.

Maximum Temperature Rise

A maximum surface temperature rise of 800° has been computed after one second of application. This, of course, is not the highest temperature rise of the brake surface. Surface temperatures at the end of a 12 second application simulating the above unit heat loading have been found to be in excess of 1200°F.

This is near the critical temperature of steel. It is therefore safe to assume that the maximum surface temperature at the end of the landing run will be at least 50 per cent above the maximum indicated after one second of application.

Effects of Brake Size

If space limitations in the wheel structure had compelled the use of two 13 × $2^1/_2$ in. brakes with proportionate brake drum mass (remembering that mass cannot be added by increasing thickness if the thermal stresses are border line), 24 lbs. of total effective drum instead of 31 would have resulted. The average drum temperature rise would have been 973° instead of 750°. The maximum surface temperature rise after one second would have been 970° instead of 800°. The maximum surface temperature rise after 12 seconds would have been 1455° instead of 1200°. These temperatures are far above the capacities of the best brake linings and have been substantiated by dynamometer tests where actual working conditions have been set up within the limits of available testing apparatus. Brake operation under these conditions results in heat checking, shrinkage and distortion of brake drums.

Service Experience and Criterion for Size

A careful study of the past performance of brakes in stopping conventional airplanes has been made. A survey has also been made of the truck industry's experience with brakes. In the latter case a common criterion for judging brakes is expressed as the number of pounds of vehicle per square inch of rubbed surface of the brake drum. Service experience with airplane brakes shows the dividing line between successful and unsuccessful operation is 47 lbs. of airplane per sq.in. of rubbed drum surface. It has been found that airplanes exceeding this amount experience acute brake maintenance problems, whereas those below this amount show a consistent record of fairly trouble-free brake performance. This figure is based purely on experience with conventional airplanes whose landing speed is very close to 70 m.p.h. Therefore, 47 pounds holds only for this landing speed. The truck industry's figures are in close alignment with this, which seems reasonable as truck operation also requires stops from approximately 70 m.p.h.

The correct loadings at other landing speeds are inversely proportional to the squares of the speeds as shown by

$$F = 47 \times 70^2/V^2 \qquad (3)$$

Where F = pounds of airplane per square inch rubbed drum surface,
V = landing speed of the airplane (m.p.h.).

From this equation the diameter and width of the brake drum surface may be determined.

A fair relationship between brake diameter D and brake width Y to properly proportion the brake is

$$D = 4.7\ Y$$

whence

$$A = 4.7\ \pi\ Y^2 = W/NF \qquad (4)$$

Where A = rubbed drum surface area per brake,
W = gross weight of airplane,
N = number of brakes,
D = brake diameter, and
Y = brake width.

All factors except Y are known. Therefore, this equation can be solved for Y, which will determine D. Computation of the brake size by this procedure requires knowledge only of the gross weight and landing speed of the airplane.

The gross weight used to determine the brake size must be the weight at which the airplane will be flown. This weight is often considerably above the original estimate. Altitude of landing fields and instrument landings must be taken into consideration as they both affect landing speed.

Effect of Taxiing on Brakes

Conditions under which the airplane must be taxied put an additional load on the brakes, as the brakes have been heated during the landing run with little opportunity to dissipate the heat. The requirement for braking during taxiing is primarily a matter of safe operation of the airplane within the limitations of weather conditions, time limitations of the schedule, and, in the case of military airplanes, the ground maneuvers necessary to land and take off in formation. Some broad assumptions will illustrate to what extent the brakes may be used while taxiing.

Assume the airplane is taxied for a mile at 30 m.p.h. in a gusty cross wind. Under this circumstance the pilot finds better maneuverability results from dragging both brakes slightly, enabling him to correct quickly for a sudden gust. If the drag amounts to 400 pounds and his average speed is 44 ft. per sec., the brakes will generate 22.6 B.t.u. per sec. Therefore, a total of 2720 B.t.u. are generated in 1 mile.

The above rate of heat generation is small compared to that in the landing run. For this reason the drum may be expected to dissipate as much as 25 per cent of the heat generated, leaving 2040 B.t.u. to be absorbed by the brake drums.

Since the total computed brake drum weight necessary to handle the landing stop is 31 pounds, the absorption of 2040 B.t.u. will result in an average drum temperature rise of 562°F. Further, since the taxi run may immediately follow the landing run, and as the landing run caused an average temperature rise of 750°, the total temperature rise after taxiing probably would be 750° + 562° or 1312°. The result of

this high temperature will be weak brakes at the end of the taxi run, because of lining "fade." It is also possible that this temperature may have burned the lining and severely damaged the brake drums. The effect of cross winds which might be reduced by the use of steerable nose or tail wheels should be considered.

In order that the brakes will withstand the most severe operating conditions, the brake manufacturer should be supplied with the turning moment induced on the airplane by cross winds, speed at which the airplane will be taxied and the probable length of the taxi run.

Dual Brakes

If the adequate brake size requires too large a wheel and tire, the airplane designer should consider the possibility of using two brakes per wheel instead of one. This will reduce the wheel size and consequently the tire size. Another advantage is that the heat from the brake is not concentrated on one side of the tire but is divided between its two beads with resultant decrease in tire temperature.

Brake Requirements for Tricycle Landing Gear

The brake criteria presented are applicable to the conventional type airplane. For the airplane with tricycle gear these criteria are altered by the following considerations.

(1) During that part of the run made with three wheels in contact with the ground, the tricycle geared airplane will have less aerodynamic drag than the conventional, unless more effective flaps are used.

(2) The rate of generating brake heat may be greater on the tricycle geared airplane. As soon as the tricycle geared airplane rolls onto the nose wheel, most of its lift is lost. Therefore, almost full brakes can be applied immediately, whereas with the conventional gear the load on the wheels increases gradually with decrease in speed. Consequently, with tricycle gear the brake drum will probably suffer more severe use, unless additional brake area is provided.

(3) Brake requirements during taxiing may or may not be more severe on tricycle geared planes. Taxiing speeds will probably increase, resulting in requirement for a greater rate of heat dissipation by the brakes. Directional stability will be greater, necessitating more brakes for emergency maneuvers. On the other hand, cross winds will probably have much less effect on the brake requirements than with conventional airplanes, because the landing wheels have been moved aft, reducing the turning moment produced by side winds.

Engineers who have had actual experience with and have made detailed studies of tricycle gears feel that increased braking should be provided. Their opinions vary between a 25 per cent increase and an increase as great as 75 per cent. Limited experience at the present time indicates that from 30 to 50 percent additional brake area will be needed on tricycle geared airplanes to give the same relative performance and life obtained with airplanes equipped with conventional gears.

Conclusion

It is hoped that a better understanding of brakes and their relationship to the airplane will result from this paper, that the need for brake standards at the airplane's inception has been shown and that discussion between airplane designer, brake engineer and operator during the conception of new airplanes will be stimulated.

Book Reviews

Soviets in the Arctic, by T. A. Taracouzio; The MacMillan Company, New York, 1938; 563 pages, $7.50.

To those whose interest in polar exploration by air is aroused by the Soviet Arctic Exhibit at the New York World's Fair, this study of the Soviet advance into the Arctic will have an exceptional appeal. To others it will be an "eye-opener" to a field of conquest in which the airplane has made a place for itself, and in which it will continue to play an increasingly important role.

The claims of the daring explorers and pilots, who visited new areas in the Arctic and Antarctic and appropriated these in the name of his country, are being seriously challenged. The U.S.S.R. has laid claim to all of the land, water, and ice north of its boundaries in Europe and Asia, clear to the North Pole. Canada and other countries are making similar claims. Under this interpretation the United States would be entitled to about 30° north of Alaska, Canada 80°, U.S.S.R. 160°, and Denmark, Norway, and Finland the remainder. As the Arctic and Antarctic are the only parts of the earth's surface where there is unclaimed territory, they will command an increasing place in international relations.

Dr. Taracouzio's book, prepared at Harvard University, gives a comprehensive review of the historical, economic, and political aspects of the Russian sector. It is a story of the penetration of the world's last frontier, to which aviation has contributed so greatly.

After the flights of exploration, it is common experience that commercial or nationalized air lines soon follow. In northern Russia and Siberia air transport is the most practicable and economical means of opening up the country. In 1933 there was only one line in operation in the Soviet Arctic. In 1936 there were ten routes, covering 11,395 miles. By this year the total has been further increased. Even in 1937 the plan was to carry 603,700 tons of cargo, 2,145 tons of mail and 10,800 passengers. This would seem incredible if the achievements of Canadian air transport did not provide something of a parallel on our own continent.

This book will undoubtedly stimulate interest in Arctic flying, as it lays emphasis on the great scientific and economic possibilities of further exploration.

The work is well documented and the maps and bibliography are invaluable aids to further study. Of particular interest to students of the history of aviation will be the record of the many flights by Russian pilots carrying out missions of exploration, rescue, and transport, and the conclusions reached by the author regarding the far-reaching implications of these undertakings.

The Royal Aeronautical Society's New Home

THE new headquarters of the oldest aeronautical organization in the world were opened formally in May and are regarded by all who have had the pleasure of seeing the building, as the most beautiful offices of any scientific organization in London.

For several years the Council of the R.Ae.S. has been making plans for securing a suitable building to accommodate the expanding activities of the Society. Last year an option was obtained on the luxurious house at 4 Hamilton Place near the Hyde Park Corner end of Park Lane. It had been the home of the late Mr. Leopold Abu, who made extensive alterations and spared no expense to make the house one of the most dignified and beautiful in London. The back of the building overlooks Hamilton Gardens and Hyde Park—one of the most delightful views in Mayfair.

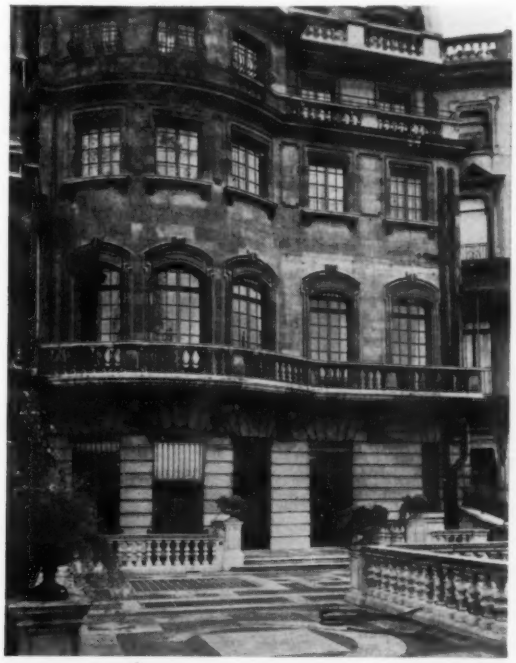
The Council of the Society obtained, through gifts, about $400,000 for leasing the building and providing for its maintenance. The gifts were made principally on a plan of seven yearly payments and are, in many cases, deductible from income taxes. As is customary in London the property is leased for a period of 29 years with the payment of ground rent. The previous owner spent over $200,000 in redecorating the premises.

The ground floor contains the Council Room, Members Reading Room, and Waiting Room. The walls of the Council Room and the Members Reading Room are lined with gold colored tapestry. The Council table is a unique D-shaped table, made of mahogany, and specially designed so that every speaker can be seen and heard clearly from any seat at the table. The Presidential chair is embossed with the Society's crest in gold.

The Members Reading Room looks out on the terrace and Hamilton Gardens. Between it and the Council Room are sliding doors which enable the two rooms to be made into one on the occasions of receptions.

The main staircase, leading to the library and committee rooms, is one of great dignity and beauty, and was designed in the spacious Victorian days when Park Lane was a center for great receptions.

For the first time in its long history, the Royal Aeronautical Society has a library worthy of the unique collection of aeronautical books, pamphlets, and rare prints which it possesses. This room was originally the ballroom and its beautifully designed proportions make it easily the most dignified library of any of the leading Societies or Institutions. It is furnished throughout in walnut, with green leather upholstery and green velour curtains. Each end of the library



Front and rear views of the new headquarters of the Royal Aeronautical Society in London. The rear overlooks Hyde Park and Hamilton Gardens and is one of the most beautiful views in the Mayfair district.

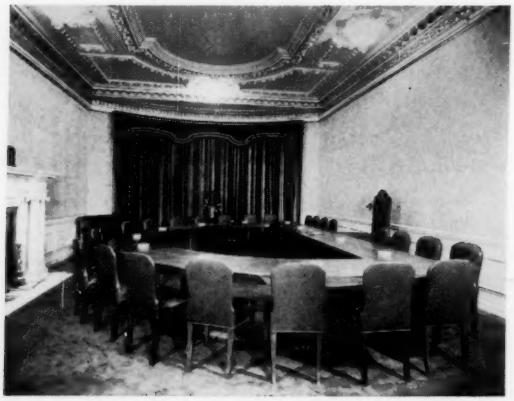
One end of the Library, which contains the priceless collection of aeronautical books acquired by the Society in the 73 years of its existence.

is pillared in marble and fitted with carved marble fireplaces. The ceiling is decorated with heraldic emblems in gold relief, an art which is now almost extinct. The bookshelves were designed to fit the proportions and dignity of the room itself. The mirrored doors give the effect of greatly increasing the size of the library. The whole of the lighting is concealed so that there is no direct glare.

On the second floor are two special Committee Rooms, where not only Committees of the Council meet, but Committees of other aeronautical and engineering Societies.

The third floor is occupied by the Secretary's office and the general offices, and the fourth floor by the store rooms for the Journal and other publications, the telephone exchange, and the accountant's office.

So that all members should have the opportunity of seeing No. 4 Hamilton Place, the President and Council invited all members and their ladies to a Reception and Dance. So many early indicated their wish to come that two nights were set aside for the purpose, June 16th and June 17th. Over 1100 members and their ladies attended on the two nights and were received by the President. The gardens of No. 4 Hamilton Place were open for the occasion and every opportunity was given for all to see the new home under the best possible conditions.



The Council room and a reception room.

Institute Notes

International Congress of the Aeronautical Sciences Postponed Until 1941

After careful consideration of the plans to hold the International Congress of the Aeronautical Sciences in New York in September, it was decided by the Council of the Institute to postpone this Congress until 1941.

It was the unanimous opinion that the engineers and scientific specialists in the United States and countries which were planning to send delegates were so occupied with problems of design and production that they would find it difficult to participate.

The plans and the program for the International Congress of the Aeronautical Sciences to be held in 1941 will be announced next year.

Honorary Fellows Elected

Each year the Fellows of the Institute elect, by secret ballot, one foreign and one American Honorary Fellow. The recipients of the honor for this year are Prof. G. I. Taylor of Trinity College, Cambridge University, and Dr. Hugh L. Dryden, Chief of the Mechanics and Sound Division of the National Bureau of Standards.

Dr. George W. Lewis, President of the Institute, presented Prof. Taylor with his certificate of Honorary Fellowship at a luncheon at the Royal Aero Club in London, on May 30th.

Wilbur Wright Memorial Lecture and European Trip of the President and Secretary

Dr. George W. Lewis, President of the Institute, delivered the Wilbur Wright Memorial Lecture on "Some Modern Methods of Research in the Problems of Flight" before the Royal Aeronautical Society in London on May 23, 1939. Before the lecture Dr. Lewis presented the Daniel Guggenheim Medal to A. H. R. Fedden, President of the Royal Aeronautical Society "for contributions to the development of aircraft engine design and for the specific design of the sleeve-valve engine" and Lester D. Gardner, Secretary of the Institute, presented the Musick Award, established by an aviation group in New Zealand, to Mr. Arthur Gouge, General Manager and Chief Designer of Short Brothers, Ltd.

After the lecture a dinner was given in honor of Dr. Lewis in the new building of the Royal Aeronautical Society. It was the first dinner given in the Society's new headquarters, and was attended by about eighty leaders of British aviation, including Sir Kingsley Wood, Secretary of State for Air.

While in Paris, Dr. Lewis and Mr. Gardner attended a reception given in their honor at the Aero Club de France by the French members of the Institute.

Leaving Paris, Dr. Lewis visited Berlin, while Mr. Gardner flew to Rome to attend the First World Congress of Aeronautical Editors, where he represented the Journal of the Aeronautical Sciences. He was the guest of General Umberto Savoja and Dr. Giuseppe Gabrielli in Turin. As a guest of the Italian Air Ministry he flew to Athens and returned to London in an Empire Boat as a guest of the Imperial Airways. Later he flew to Holland to visit Mr. A. Plesman of the K.L.M. and Dr. E. B. Wolff, Director of the National Luchtvaartlaboratorium at Amsterdam.

In Berlin Mr. Gardner was a luncheon guest at the Haus der Flüger of the D.V.L. and attended a meeting of the Deutscher Akademie, where he met many German members of the Institute. He flew back to London via Oslo, Norway. Before leaving London Mr. Gardner attended the dinner given in honor of the 30th anniversary of the founding of the Handley Page Company.

Both Dr. Lewis and Mr. Gardner were shown great attention and courtesy by the Royal Aeronautical Society. Mr. A. H. R. Fedden, President, Capt. A. Laurence Pritchard, Secretary, and the entire staff arranged visits to interesting aeronautical establishments and made it possible to renew acquaintances with many friends.

Dr. D. R. Pye gave a dinner in honor of Dr. Lewis and Mr. Gardner at the Athenaeum in London. Many of the leading aeronautical scientists of England attended.

Gifts to the Institute

The Hart O. Berg Collection

While in Paris, Dr. Lewis and Mr. Gardner were asked by Mr. Hart O. Berg to discuss with him the disposition of his collection of early aeronautical papers, including many interesting photographs and clippings pertaining to the early work of the Wright Brothers. Mr. Berg offered to present the collection, which is probably unique in the world, to the Institute.

At the meeting of the Council on July 20, the following resolution was adopted:

WHEREAS, Mr. Hart O. Berg has presented to the Institute of the Aeronautical Sciences his valuable and rare collection of photographs, books, and clippings which contain much unique material on the early work of the Wright Brothers and other aviation pioneers,

THEREFORE, BE IT RESOLVED that the Council express for the membership of the Institute great appreciation for Mr. Berg's generosity;

AND BE IT FURTHER RESOLVED that Mr. Berg's name be added to the list of Benefactor Members of the Institute.

Mr. Berg has had an interesting career. He sponsored the first public flights of the Wright Brothers in Europe, organized the world's first aviation company and designed some of the earliest airports in France. For three years he was the representative of the Wright Brothers in Europe. He built the first large automobile factory in France and introduced Simon Lake's submarine in Europe. Browning machine guns, developed under his direction in Hartford, Connecticut, were manufactured by him in Belgium. Later he became general manager of the large national arms factory in France.

Mr. Berg was born in Philadelphia, March 23, 1865, and was educated in Belgium. In 1908 he became associated with the Wright Brothers and leased the race track at Le Mans, France, for the first public demonstration flights of Wilbur Wright. Mr. Berg took Orville Wright to Berlin where flights were made at Templehof Field, now the site of Berlin's great airport. His wife was the first woman to fly as a passenger in an airplane.

Mr. Berg appointed his friend, Mr. Luis de Florez, as Custodian of the collection. Mr. de Florez is now rearranging the papers and placing them in permanent bindings.

The Institute is indebted to Mrs. Yount, wife of Brig. Gen. Barton K. Yount of the Air Corps, for her cooperation in making possible the presentation of the Hart O. Berg Collection to the Institute, since Mr. Berg had previously offered to present it to her.

Library Gift from Mr. C. R. Fairey

While Dr. Lewis and Mr. Gardner were in London, Mr. C. R. Fairey offered a gift of one thousand dollars to provide the Institute with English technical books for its library. The selection of the books is being made by the Royal Aeronautical Society and Mr. J. E. Hodgson, the Honorary Librarian. As an

expression of the Institute's appreciation for this generous gift, the Council at its last meeting voted Benefactor Membership to Mr. Fairey.

R.Ae.S. Journals

The Royal Aeronautical Society has generously offered to present to the Institute library, copies of all of the R.Ae.S. Journals that are available in their files. This gift will supplement the collection the Institute now has.

Technical Files

Col. V. E. Clark has presented to the Institute library the valuable collection of technical data which he has been assembling for many years. These will add greatly to the technical value of the Institute library.

A Giffard Souvenir

Charles Dollfus, Director of the Musée de l'Aeronautic in Paris, has presented to the Institute a souvenir bottle in the form of Giffard's captive balloon of 1878. Mr. Dollfus has what is probably the finest private collection of aeronautical books and art objects in Europe.

Models

The Institute has, on exhibition at the New York Museum of Science and Industry, a collection of about fifty models of airplanes. The following models have been presented to the Institute by manufacturers and can be seen at the museum:

Original Wright airplane; Beechcraft F 17 D; Beechcraft D 17 R; Boeing 307; Consolidated PBY-1; Curtiss-Wright P-36-A, YP-37, Goshawk, Shrike, SOC-1, Y1A-18; Douglas DC-3, DC-4; Glenn L. Martin Model 166; Lockheed 14; North American NA-25, NA-49; Northrop A-17A; Pitcairn Autogiro; Sikorsky S-43; United-Vought Corsair SB2U-1; Vultee V11-GB2.

Breguet 690; Bristol "Blenheim"; Caproni Ca 325, Ca 900; Fairey "Battle"; Handley Page "Hampden"; Hawker "Hurricane"; Macchi C-200, M.C.-72; Potez 63; Savoia-Marchetti SM-79; Short-Mayo Composite; Westland "Lysander."

Several models from the Peter R. L. Brooks Collection are also on display.

Clippings on Famous Flights

Mr. Henry A. Ramsey, of New York, who has been collecting clippings about famous flights for twenty-five years, has presented his collection to the Institute. They supplement the more recent clippings that are on file and will make a valuable addition to the information section of the Institute.

Air Course Computer

The Deutsche Luft Hansa has presented the Institute with a Plath Computer for pilots. It will be available for inspection by members at the offices of the Institute.

Necrology

Lorillard Spencer

Lorillard Spencer, a Founder Member of the Institute, died at Newport, Rhode Island, on June 9, 1939, after a five year illness. He was 55 years old.

Mr. Spencer was educated at St. Paul's School and Columbia University. He had a distinguished career in both civil and military life.

As a Major of the 369th Infantry, a negro regiment, he saw active service in France, and was seriously wounded. He was awarded the Distinguished Service Cross for extraordinary heroism.

After the war he became interested in aviation, bought an airplane, and learned to fly. In 1921 he became President of the Witteman Aircraft Corporation and, in 1922, President of the Atlantic Aircraft Corporation, builders of the Barling Bomber. Later he became President of the Fokker Aircraft Corporation of America.

Mr. Spencer's interest in the work of the Institute led him to present several valuable books and souvenirs to the library.

Adolph Karl Rohrbach

Dr. Adolph Karl Rohrbach, an Associate Fellow of the Institute, died in Germany on July 8, 1939, at the age of 51.

Dr. Rohrbach was widely known as one of the pioneer German airplane constructors. In 1914 he became an airplane designer with the Zeppelin-Werke at Friedrichshafen, and from 1916 to 1921 was chief designer for the same firm's factory at Berlin-Staaken. He designed the 1000 hp., all metal 20 passenger Staaken transport planes.

In 1922 he founded the Rohrbach Metal Airplane Company, which specialized in the construction of multi-motored metal flying boats. The planes were assembled at his factory in Copenhagen, Denmark. In the fall of 1923 the first flying boat of the Rohrbach-Ro II type, powered by two Rolls-Royce Eagle IX engines, established ten world records. The plans and license to construct for that type and the subsequent Rohrbach-Ro III were bought by Great Britain and Japan. In 1927 Dr. Rohrbach abandoned the manufacture of military planes and concentrated on the Rohrbach-Romar transport planes for the Lufthansa.

In 1929 he established the Metal Flying Boat Corporation in Delaware, Maryland. He returned to Germany in 1931. For the next two years he worked on a new invention, and in January, 1933, announced the perfection of his plans for a rotor type airplane.

In 1934 he became technical head of the Weser Flugzeugbau Gesellschaft, a subsidiary of the Deutsche Schiffs-und-Machinenbau-Aktiengesellschaft, Bremen, with factories at Bremen and Berlin.

Dr. Rohrbach was educated at Gotha and Coburg, and later at the Technische Hochschule at Darmstadt, where he received the degree of Dipl. Ing. In 1921 he received the degree of Dr. Ing. from the Technische Hochschule at Charlottenburg and an honorary degree of Dr. Ing. in 1929 from the Technische Hochschule at Danzig. He was the author of many technical articles in aeronautical publications.

Aeronautical Reviews

These brief reviews of recent articles on aviation subjects are published by the Army Air Corps for the information of its officers, and are printed here each month by permission of the Chief of the Air Corps

Aerodynamics

The 1939 (27th) Wilbur Wright Memorial Lecture—Some Modern Methods of Research in the Problems of Flight. G. W. Lewis. Three special types of wind tunnel at the N.A.C.A., each having application to a special field of aerodynamics directly related to fundamental problems of airplane design, and some research results obtained in them are described, including: the low-turbulence wind tunnel and comparison of wake behind airfoils; the gust tunnel, the N.A.C.A. V-G recorder, problems investigated, and graphs showing the acceleration of an airplane in gusts of various gradients; and the free-flight wind tunnel, investigation of stability and control problems, and some results obtained. Research in the Wright brothers' wind tunnel, the balances which they employed for measuring forces, and trends of wind tunnel development, indicating the tendency to become more specialized, are also discussed. *Royal Aeronautical Soc. Preprint for Meeting*, May 25, 1939, 30 pages, 21 illus. Abstracts and editorial comment. *Aeroplane*, May 31, 1939, pages 705–707, 7 illus. *Flight*, June 1, 1939, pages 567–570, 12 illus. *Engineer*, June 16, 1939, pages 743–946, 6 illus. *Engineering*, June 9, 1939, pages 686, 694–696, 6 illus.

Davis Low-Drag Wing. Most noticeable physical characteristic of the Davis airfoil is the reflex nature of the curve, obtained largely from the convex shape of the lower surface. Development is said to result from a new mathematical formula developed from extensive study of the rotor lift theory. Shape may be varied through changes in the formula to produce wing sections of the desired characteristics, and it is reported that for each upper surface curve so developed a corresponding lower surface curve is produced to complete the airfoil. In wind-tunnel tests at the California Institute of Technology the airfoil has been shown to have a high-slope lift curve, developing its lift at relatively low angles of attack, a relatively low drag curve, and a stable center of pressure. Brief reference only to airfoil incorporated in the Consolidated Model 31 flying boat. *Aviation*, June, 1939, page 68.

The Wing-Beat of Pigeons. G. Guidi. Constant flight characteristics of birds belonging to any given species, and the author's method of obtaining, approximately, a cinematographic reproduction of three geometrical projections of the wing beat. Trajectory in space of a pigeon's wing tip during an entire beat, and the speed and acceleration reached by it are determined. A study of the photograms, while it shows, in the downward phase, positions and attitudes which are natural and might be foreseen, reveals in the upward phase movements which are unexpectedly complex and attitudes which would be incredible were they not substantiated by photographs. Long translation from *L'Aérotecnica*, February, 1939. *Jour. Royal Aeronautical Soc.*, June, 1939, pages 457–466, 5 illus., 1 table, 27 illus. on sup. plates.

TESTING EQUIPMENT

Technical Notes. Apparatus for taking cinematographic views registering 80,000 images per second has been developed by Allgemeine Elektrizitats Gesellshaft and has been used in the study of the formation of shock waves on projectiles. Film is unrolled continuously before a group of prisms turning at great speed before the principal objective. Brief note only. *Les Ailes*, June 15, 1939, page 7.

Aircraft Design

An Empirical Theoretical Method of Parasite Drag Prediction. W. N. Hammond. Empirical-theoretical method is developed in which the classification is analytical, and it is demonstrated that a reasonably precise estimate of parasite-drag coefficient can be computed from known dimensional characteristics of the airplane under consideration. Classification factor is derived from the ratio of speed for minimum drag to maximum speed, a low value of this ratio being indicative of high maximum speed, high ceiling, and high rate of climb. Estimated parasite-drag coefficients obtained are the absolute mean values computed from the known dimensional characteristics of 75 airplanes of widely divergent dimensions and maximum speeds ranging from 85 to 365 m.p.h. Development of the classification factor proceeds with a derivation of the basic expression for computation of velocity at which drag will be a minimum. *Aero Digest*, June, 1939, page 51, equations.

High Speeds and the Shock Stall. W. F. Hilton. For really high speeds, the high-wing monoplane with an upper wing surface absolutely clear, low aspect ratio, and pusher engines in the wings are required. Reasons for these requirements and compressibility effects at very high speeds are discussed. A design is suggested for a single-seater airplane which could do 550 m.p.h. today but which is laid out to do 600 m.p.h. when more powerful engines become available. Estimated loaded weight 4000 lb. Landing speed 95 m.p.h. Maximum lift coefficient 1.95 for landing. Wing loading 45.33 lb./sq. ft. Area 88.3 sq. ft. Span 15 ft. with root chord of 7.5 ft. for an elliptic plan form with aspect ratio of 2. N.A.C.A. 0012 wing section. Total drag coefficient for whole airplane 0.026. Single pusher engine with oppositely rotating propellers. Six-foot propeller having tip speed 0.95 times speed of sound and to be operated at 2200 r.p.m. Reasons for each of these specifications are given.

Airplanes of the future will have normal propellers for take-off and alighting but will fly by some sort of reaction jet or by rocket propulsion, according to the author's predictions. Royal Aeronautical Society paper and illustrations from C. H. Lock's paper of 1937 on compressibility. *Aeroplane*, June 7, 1939, pages 731–732, 4 illus.

Three Interesting Projects. Three projected designs of transport airplanes outlined by General Aircraft, Ltd., are for a 35-passenger four-engined low-wing monoplane with a range up to 2720 miles at 200 m.p.h., and for a two-engined transport to carry 24 passengers and to have a range up to 2380 miles at 180 m.p.h., the latter being worked out in both high- and low-wing versions. All projects have 1380-hp. Bristol Hercules VI radial sleeve-valve engines. None of the designs will be built as they stand but General Aircraft is considering the use of some of the data and have set out their ideas of layout, size, performance, power, furnishing, and comfort to invite comment and criticism. All the fuselages are of true streamlined form and all the airplanes have pressure cabins, fully retractable tricycle undercarriages with double main and nose wheels, and upper-surface Fowler flaps. In the 24-passenger high-wing transport, two 50-hp. aircooled engines to be run at 25 hp. each to supply the supercharged air for the cabin, are located outside the sealed portion at the back, where they would not be damaged in a forced alighting. Specifications for power plants, weights, speeds, ceilings and ranges are given for the two types as well as three-view and layout drawings. *Aeroplane*, May 31, 1939, pages 712, 714, 4 illus.

Stress Analysis and Structures

Elastic Stiffnesses of a Skin-covered Framework. E. W. H. Thompson. Effects upon flexural and torsional stiffnesses of a wooden box-wing test specimen due to different dispositions of the grain of thin ply covering. Wooden wing shell possesses maximum flexural stiffness when the three-ply grain is disposed spanwise, and minimum flexural stiffness when the three-ply grain is disposed at 45° to the span. If diagonal tension fields are developed under torsion, then the shell possesses maximum torsional stiffness when the three-ply grain is disposed at 45° to the span. Otherwise, when the three-ply grain is disposed at 0° and 90° to the span, torsional stiffnesses are equal. Under combined bending and torsion the shell possesses a maximum stiffness against flutter when the three-ply grain is disposed spanwise. Fore-and-aft disposition of three-ply over the leading edge offsets the loss of some small portion of flexural stiffness by the greater gain in ease of manufacture. *Flight, Aircraft Engr. Sup.*, June 1, 1939, pages 17–21, 6 illus., 8 tables, 13 equations.

Formica Develops Strong Light-Weight Material. Pregwood consists of thin laminations of wood impregnated with phenolic resins and vulcanized into a hard homogeneous sheet. It is said to be highly resistant to moisture absorption and is adaptable where rigid maintenance of dimensions is required under all weather conditions. Pregwood is lighter than aluminum (specific gravity 1.35) and has a flexural strength of 25,000 to 30,000 lbs./sq.in. Tested parallel to the laminations it will stand 60 v.p.m. which establishes it as a fair electrical insulating material. Coefficient of thermal expansion is low. Short description. *Aero Digest*, June, 1939, page 113.

Tables of Moments and Deflections for a Rectangular Plate Fixed on All Edges and Carrying a Uniformly Distributed Load. T. H. Evans. Maximum moments and deflections for all side ratios between 1.0 and 2.0 by intervals of 0.1, are determined following Hencky's procedure. Growing out of the necessity for solving eight groups of simultaneous equations in twelve unknowns, a short cut on the usual trial and error process of solution is developed. *Jour. Applied Mechanics*, March, 1939, pages A-7–A-10, 2 illus., 2 tables, 13 equations.

In Search of Safety. Story of the Handley-Page slot. Recent slot development has been in the direction of lift slots and slotted flaps over the inner portion of wings, and automatic leading-edge slots and slotted ailerons over the outer. Westland Lysander is the most outstanding British example in which the operation is entirely automatic. Leading-edge lift slots open when a certain angle has been reached, and, being linked with the flaps, pull these down at the right moment. The Messerschmitt Me.109 and Savoia-Marchetti S.M.79 are illustrated as other examples of recent airplanes to make use of slots and slotted flaps. Development of the Handley-Page slot is traced with illustrations of early aircraft fitted with them. *Flight*, June 22, 1939, pages 635–637, 8 illus.

Fundamentals of Stressed-Skin Design. H. E. J. Rochefort. Problems encountered in the practical application of stressed-skin design, and the method of attack and solution. Basic formulas given in the first issue cover: strength of thin plates under compressive loading; strength of thin plate edges, simply supported, subjected to shear loading; combined direct and shear loading; incomplete diagonal tension fields; and diagonal tension field theory in regard to tensile stress in web or skin, compression load in compression flange of spar, and load in vertical struts.

Second issue—Determination of loading on wings and fuselages (bending loads and direct shear, and torsion loading); determination of stresses in wing structures due to bending, direct-shear, and torsional-shear loads, axial constraint, and the combined total stresses; and determination of stresses in fuselage structures due to bending loads, direct shear, and torsional shear, the combined stresses, and stressing of fuselage diaphragms. *Aeroplane*, June 14 and 21, 1939, pages 760–763 and 799–802, 20 illus., 30 equations.

Models in Structural Research. D. Williams. Models as an aid to the designer in solving difficult problems in stressed-skin structures. Relations connecting the behavior of the model to that of the full-scale structure are examined. Model and full-scale displacements and how to deal with structure weight are considered. Linear and angular stiffnesses, and natural frequencies of the linear and angular motions are taken up. Use of models for strength investigations in regard to failure by excessive primary stresses, failure by elastic instability and secondary failure is described. Formulas are developed for stiffness and strength investigations. *Aircraft Engineering*, June, 1939, pages 231–232, 32 equations.

Note on Lord Rayleigh's Reciprocal Theorems in Elastic Systems. J. Morris. Short historical review of the development of main lines of attack on problems of the statically indeterminate type. From Rayleigh's general theorem a variety of reciprocal properties pertaining to particular cases may be deduced. Three important ones are suggested for a rod (not necessarily uniform in section) supported horizontally in any manner. Short article. *Jour. Royal Aeronautical Soc.*, June, 1939, pages 467–468.

Stress Analysis of Thin Metal Construction. H. L. Cox. Buckling of flat panels, equivalent width, and curved panels; stress analysis of cylinders in bending, and results of three tests on a complete tube, quadrant test piece, and single stringer; ultimate stress carried by stringers attached to the sheet in regard to effect of curvature, fixity effect at frames, interaction of sheet and stringer, local instability, and overall instability; stress analysis of cylinders in torsion; and effect of holes and concentrated loads in regard to stiffening of small holes, effect of tension diagonal stresses on edge members, and diffusion of concentrated loads. Theory and test results. *Royal Aeronautical Soc., Preprint for Meeting*, May 4, 1939, 35 pages, 20 illus., 1 table, 4 equations.

The Stressing of Thin Rings. R. A. Fairthorne. Simplified and complete method for the solution of continuous rings. Simplification of the standard method, allowance for peripheral thrust and tension, geometry of deforma-

tion, energy equation, fundamental deflection formulas, representation of peripheral stress by fictitious hydrostatic pressure, and validity of textbook and modified approximations are considered. Approximation given by the textbook theory for the deflection of circular rings is valid so long as the ratio of the algebraic sum of the loads to the stiffness divided by the square of the radius is less than two. The cases of two opposed radial loads, two opposed inward radial loads with two equal opposed outward loads perpendicular to them, and a distributed load proportional to its distance from a fixed diameter are considered. Approximation given can be extended to rings that are slightly elliptical in much the same way as is the extension of the theory of straight struts to cover struts that are almost straight. *Aircraft Engineering*, June, 1939, pages 228–230, 237, 3 illus., 18 equations.

Structural Research in Aeronautics. A. G. Pugsley. Structural research workers, as well as being in close contact with aircraft constructors should have an appreciation of the airworthiness standpoint and some aerodynamic knowledge. They should make themselves at home with the idea of statistical theory to acquire a detailed knowledge of existing structural statistics and to interest themselves in the collection of further data. Difficulties arising from the rapid growth of aeronautics, and probable scope of structural problems in the future are considered. By a discussion of accuracy questions, the special position of aeronautical structural design is brought out and the need for a balanced outlook in the conduct of structural research and of routine stressing is emphasized. Strength, stiffness, and construction principles and ideas are considered in relation to the design history of aeronautical structures, and in the section on design rules the possibly impending development of "rules-of-thumb" is taken up. Attention is drawn to outstanding points regarding conduct and trend of structural research in relation to airworthiness. *Aircraft Engineering*, June, 1939, pages 225–227.

Tapered Beams. E. H. Atkin. Part III of this paper which dealt with tapered beams with uniform thin webs and concentrated booms of constant cross-sectional area, is criticized by E. Reissner. Since in reality stresses due to a concentrated force applied at the apex of the beam ought to be—for finite area of the booms—finite themselves at the point where load is applied (they are certainly finite for the booms minus web) there is some reason to doubt the validity of Mr. Atkin's solution. Brief letter with author's reply. *Aircraft Engineering*, June, 1939, page 238.

Aircraft for High-Altitude Flight

High Altitude Flying Observations. D. W. Tomlinson. High-altitude flight tests with the Douglas DC-1 and Northrup Gamma, undertaken for Transcontinental and Western Air, and test results obtained are described in detail, including supercharger methods, oxygen system, fuel pressure problems, power-plant operation, and level speeds at altitudes. Conditions encountered in several interesting overweather flights at high altitude are discussed.

1939 will see the level of air-transport cruising operation raised to between 16,000 and 20,000 ft. Pressure cabin and cockpit will be equipped to maintain 8000-ft. pressure at the lower level and 12,000-ft. pressure at 20,000 ft., which upper level will be used in emergency. Due to the fact that high-altitude operation involves long flights and at extreme heights of 30,000 ft. or above, flights of less than 2000 miles are inefficient; payload is a critical factor. Cost per mile of operation increases due to greater initial cost of equipment with resulting higher depreciation charge. *S.A.E. Preprint for World Automotive Engineering Congress*, May–June, 1939, 14 pages, 2 illus., 2 tables.

Aircraft Maintenance

Airline Fleet Maintenance: The British Airways Method. Complete servicing of American aircraft and engines at the Heston shops of British Airways. Ingenious methods of performance checking, and instruments used in tests of various parts are described, especially an hydraulic device which separates the two components of the crankshaft. Pressure required to separate these components is around 15 tons. Same device is used in reassembling the crankshaft. *Flight*, June 15, 1939, pages 616–618, 4 illus.

Aircraft Manufacture

American Manufacturers Have Spent $44,000,000 for Research. According to a comprehensive survey of 37 manufacturers producing airplanes, engines and propellers in the United States during the period 1934–38, inclusive, these manufacturers have spent $44,000,000 in research and development work to improve the airplane. Brief reference only to survey. *U.S. Air Services*, June, 1939, page 37.

Large-Scale Production in Wood. Methods employed in the manufacture of the Airspeed Oxford are described in very great detail, covering: planning system; structure of the center section and method for producing it; production of the main planes at the Acton factory of Hooper and Company as a subcontract; wood detail shop and methods of producing the tail plane, elevator, fin, rudder, fuselage sections, crash bulkhead, various odd wooden components, and assembly of the pilot's cabin top; manufacture of wood components for the fuselage; fitting shop; sheet-metal work; drop-hammer shop; machine shops; tool room; and final erection. Structural parts of the Oxford and jigs and other tools used in producing them are illustrated in a great many drawings and photographs. Firms supplying materials and parts for the production of the Oxford are listed. *Aircraft Engineering*, June, 1939, pages 243–253, 257, 55 illus.

Addition to the Glenn L. Martin Factory. Newest addition to the factory at Middle River, Md., is a 440,000-sq. ft. concrete, steel and glass structure which required only 77 days to build, establishing a new construction record. Basement floor affords unobstructed interior headroom of from 10 to 13 ft., and on the main floor adjacent the main assembly hall, headroom ranges from 18 to 28 ft. with adequate daylighting throughout from monitors above and "all-glass" walls on three sides. Few details. *Aero Digest*, June, 1939, page 65, 4 illus.

A Visit to the Assembly Line of the Factory of Nantes-Bouguenais. M. Victor. Account of visit to the plant producing the Morane-Saulnier 406 pursuit airplane in a large series, and a description of the method of assembly. Parts are produced in other plants and assembled there. *Les Ailes*, May 25, 1939, page 8, 4 illus.

Assembly line of French Factory Making Morane Fighters. Photograph only. *Aeroplane*, May 31, 1939, page 687, 1 illus.

America's Answer—Gearing Our Aviation Industry to the National Defense. T. P. Wright. Formula, used by the author during trips to Europe, is that 1000 men on the direct labor force could produce 10 airplanes a month of a type having a gross weight of 10,000 lb. Results of applying this formula proved quite good when check against actual output could be made. It showed somewhat greater efficiency for the United States than for most countries abroad. Basic scheme proposed is to determine actual outputs from plants operating at approximately one-shift capacity at the present time and then to extend these figures to cover the whole industry, first on a one-shift basis and then to total capacity, properly "weighting" for such factors as quantity and type of construction.

Tables show: production possibilities (one-shift and capacity); size of U.S. aircraft industry (present and expanded); Government cost of maintaining a fixed size of Air Force; expanded U.S. Air-Force aircraft requirements by July 1, 1941; estimate of spares and total "equivalent" airplanes and engines; assumed composition of U.S. Army and Navy Air Forces; average size and unit price of airplanes; production capacity (airplane); U.S. airplane industry (military, export and transport); production capacity (engines and propellers); U.S. aircraft engine and propeller industry (military, export and transport); table of funds required (2 years); indicated appropriations for procurement of complete airplanes; the airplane and engine "sales dollar;" average plane cost; causes of increase in price of airplanes; and comparison with other years and other countries.

Author proves that industry can definitely do the job with only a very small additional "balancing" expansion of about 10 percent of floor space. He recommends that the industry does not expand any further than suggested, at least until there is a commercial need definitely in sight. Emphasis is placed on research, and three types of expansion are discussed. *Aviation*, June, 1939, pages 26–29, 78, 80, 82, 84, 3 illus., 16 tables.

Aircraft Performance

Turns in a Wind. D. C. Romick. Airplane must increase its ground speed by twice the wind velocity when flying into the wind and making a 180° turn at a constant airspeed. On turning from downwind to upwind, its actual velocity decreases by the same amount, which might seem to have a disturbing influence on uniform flight, and accidents are sometimes attributed to it. Actually, airplane is not affected in turns or at any other time by a steady wind as long as it does not touch the ground or anything connected to the ground. Path of the plane relative to the ground is shown for an airspeed of twice the wind velocity, and the method by which it is derived is explained. The forces acting on the airplane are investigated, and it is shown that the wind has no effect whatever on the behavior of the airplane, regardless of wind velocity and direction, except to alter the course of the airplane over the ground. Discussion applies to motion in any plane, vertical as well as horizontal. In a steady wind for loops, immelmans, wing-overs or any other maneuver, there is nothing to be gained by considering wind direction. *Aero Digest*, June, 1939, pages 81–82, 133, 5 illus., many equations.

The Flying Controls of the Aeroplane. G. T. R. Hill. Academic aspect of control problems, underlying causes of the behavior of the airplane when maneuvering, and the possibility of setting the whole subject on a firmer theoretical foundation are considered, including: relation of control to stability; experiments on harmony of controls; pilots' opinions on control and stability; quantitative measurement of control; early attempts to measure control; quantitative specification of control; definition of "pleasant" control; position, velocity, and acceleration controls; and lag.

Recent experimental work helping to solve immediate day-to-day difficulties which arise with faster and larger airplanes are discussed. Theory and practice of maintenance of trim, change of trim with throttle opening and with flap operation, and ground influence on trim are taken up. Recent developments described include improved method of balancing control surfaces, a quickly operable flap, aileron control replacement, two-control systems, and flying models. *Royal Aeronautical Soc., Jour.*, June, 1939, pages 411–440, 8 illus.

Testing Equipment

Analysis of Landing and Take-Off. Photographic system developed by Eastman Kodak Company consists of four spring-driven motion-picture cameras with electrically operated single-frame releases. One pair of cameras is set on a short base of 60 ft., and the other on a long base of 300 ft. Coordination of films and timing devices, together with a projector on which images produced by the two cameras of a pair are projected, and which is provided with reference markers, enables complete space triangulation to be carried out and exact position of the plane in horizontal and vertical distance at any instant of time is recorded. Very brief note. *Scientific American*, June, 1939, page 375, 1 illus.

A Method for the Photographic Recording of Take-Off and Landing Performance. J. B. Douglas and J. B. Mills. All necessary performance data concerned with the take-off and landing of aircraft can be obtained in a cheap and efficient manner by the De Havilland method which was developed in connection with research into variations in take-off and landing of different aircraft on various airports and under numerous conditions of loading airport surface and atmosphere. Complete path of the machine from start of the take-off run to beyond the screen is recorded on a single photograph and from it the reduction of data is done readily and simply. Accuracy obtainable is sufficient to fix the position of the aircraft to within ±2 ft. Four persons at present form the total ground staff; and with an improved camera now under construction one of these is eliminated. Long description of camera and its operation, and details of its use in the measurement of wind velocity gradient. *Royal Aeronautical Soc., Jour.*, June, 1939, pages 441–456, 14 illus., 1 table, 10 equations.

Aircraft

Sabca S-47 Two-Seater Fighter. A. Frachet. This fighter, designed also for missions of attack and long-distance reconnaissance, is equipped with a Hispano-Suiza 12-Ycrs cannon engine developing 835 hp. at 4200 meters. At this altitude maximum speed is 480 km./hr. and cruising speed 350 km./hr. The prototype, studied by Belgian engineers, has been constructed in Italy by Caproni but the Sabca proposes to produce it in series in its plant at Brussels for export. Time to climb to 4000 meters, equipped as a fighter, 6 min. 40 sec., and equipped as an attack airplane 8 min. Duration as a fighter 2 hr., and as a reconnaissance airplane 4 hr. 30 min. Long description of construction with armament and loads for the three missions characteristics and performances. *Les Ailes*, June 6, 1939, page 9, 3 illus., 2 tables.

Canada

Canadian Car & Foundry's Single Place Fighter. Gregor FDB-1 highly maneuverable, all-metal, gull-wing biplane equipped with slots and flaps and with retractable landing gear is adaptable as a fighter or dive bomber. Armament includes two 0.50-caliber machine guns (synchronized with engine and mounted in center section forward of instrument panel), boxes for 1000 rounds of ammunition and two 116-lb. bombs. Airplane is stressed for engines ranging from 750 hp. to 1200 hp. Wing span 28 ft. Wing loading 21.9 lb./sq.ft. Maximum speed, at 7700 ft. with Pratt and Whitney

Twin Wasp Junior 750-hp. engine, 300 m.p.h. Cruising speed 255 m.p.h. Rate of climb 3520 ft./min. Cruising range 963 miles. Long description, characteristics and performance. *Aero Digest*, June, 1939, pages 89–90, 6 illus. Description. *Flight*, June 8, 1939, page 586.

FRANCE

Caudron C-860 Racing Airplane. A. Frachet. Caudron C-860 airplane which has been ordered by the French air minister, will be entrusted to A. Japy who will undertake important high-speed trials. Airplane has a very slender monoplane wing and empennages of the same form as those of the Simoun. Relative position of the empennages and landing gear is the same also. Wing is designed in one piece. With overload for long-distance flights, total weight of the C-860 can be lifted up to 2300 kg. at which range is 7100 km. at 290 m.p.h. At a total weight of 1650 kg., maximum speed is 340 km./hr. at 2500 meters. Range 8000 km. with a total weight of 2400 kg. and cruising speed of 290 m.p.h. Renault 6-Q 240-hp. engine. With engines of 8 to 6.5 liters the C-860 can beat the distance and altitude records of the first and second categories. Long description. *Les Ailes*, June 8, 1939, page 9, 3 illus., 2 tables.

This Amphibian Uses an Automobile Engine. Proposed three-place amphibian with tricycle landing gear has been designed by M. Deckert to use a Delahaye 3.5-liter automobile engine (110 hp. at 2800 r.p.m. cruising and 135 hp. at 3900 r.p.m. for take-off) without any modification, and with all its accessories. Engine is located in a nacelle above the wing and at the center of gravity. Coatal electromechanical speed box, with which the engine is normally equipped, is used for varying propeller pitch. Second speed is utilized for take-off and climb at low speeds, slots opening and flaps lowered. *Les Ailes*, June 15, 1939, page 8, 2 illus.

GERMANY

Development of the Focke Helicopter. H. Focke. Analytical and experimental information regarding helicopters in existence prior to 1932 is briefly reviewed, and the fundamental requirements to be met and procedure adopted to satisfy them are taken up. Analytical discussion is based on the Glauert-Lock theory of the autogiro rotor, and various steps in extending the theory to cover the helicopter rotor are shown in an outline. Construction and testing of the first machine are described, together with its successful flights. *A.S.M.E. Trans.*, April, 1939, pages 177–189, 22 illus., 1 table, 2 equations.

Dornier Transatlantic Flying Boat. Dornier Do. 26 Seeadler catapultable flying boat has wing-tip floats retractable into the wings in flight. Hull is of the two-stepped all-metal type, divided into eight compartments by water-tight bulkheads. Four 6-cylinder Junkers Jumo heavy-oil engines, each developing 600 hp., are placed back to back. Wing span 98.5 ft. Load carried 21,640 lb. Maximum speed at sea level 208 m.p.h. Cruising speed 193 m.p.h. Landing speed 68.4 m.p.h. Maximum range 5600 miles. *Engineering*, May 26, 1939, pages 618–619, 5 illus.

Moeller Stuermer V Light Single Seater. A. Frachet. This airplane last April broke the world speed records over 100 and 1000 km. for airplanes of 2-liter cylinder capacity. Powered with a Zuendapp engine of 53 hp. it has a cruising speed of 210 km./hr. and climbs to 1000 meters in 3 min. Maximum speed at ground level is 175 km./hr. Long description, characteristics and performance. *Les Ailes*, June 15, 1939, page 9, 3 illus., 2 tables.

GREAT BRITAIN

The History of Handley Page Ltd. C. G. Grey. History of Handley Page, Ltd., and C. G. Grey's comments on the company's war activities and various types of airplanes developed during the past thirty years. *Aeroplane*, June 21, 1939, pages 787–798, 46 illus. History and airplanes developed. *Flight*, June 22, 1939, pages 630h–630l, 631–635, 49 illus.

De Havilland "Flamingo" Transport. All-metal high-wing twin-engined transport airplane has been developed for use on wheels, floats or skis. Four alternate cabin arrangements are available, for 12, 14, 17 or 20 passengers. Two Bristol Perseus XIIc sleeve-valve engines developing 890 hp. for take-off. Wing span 68 ft. Overall length 50 ft. 7 in. Wing loading 26.6 lb./sq.ft. Payload 2613 lb. Maximum speed at 7500 ft. 243 m.p.h. Cruising speed at 10,000 ft. 204 m.p.h. Cruising range 1305 miles. Rate of climb 15,000 ft./min. Long description. *Aero Digest*, June, 1939, pages 90, 133–134, 2 illus.

Direct Take-off Makes Good. C. M. Poulsen. The C.40 autogiro now ready for production behaves in the air pretty much like the C.30. Rotor seems to be very smooth, and the way it irons out bumps is quite remarkable. Landing is quite incredible with no run at all. Inspite of side-by-side seating machine looks slimmer than its predecessor. Streamline casing around the upper part of the pylon, a windscreen of generous dimensions, a differential tail with incidence larger on one side than on the other, and a streamlined fairing on the rudder are new features.

The C.40 can descend very nearly vertically although for the last few feet some forward speed is necessary if a light landing is to be made. Take-off is now simplified by the use of jump starting. Absence of "sink" from top of the jump is due partly to the new rotor head, differing in detail from the "autodynamic" head of the experimental machine, and partly to technique of the pilot in letting the nose drop slightly in the jump so that lift of the rotor is inclined forward and assists the propeller in pulling the machine along. Value of the autogiro to the Army and Navy is pointed out and flying impressions are described. Five have been ordered by the British Air Ministry. *Flight*, June 8, 1939, pages 580–582, 6 illus.

The Handley-Page Hampden Bomber. A. Frachet. Disposable load (equipment and armament) 1631 kg. Maximum speed, with 8525 kg. total weight, 427 km./hr. at 4700 meters. Time to climb to 4600 meters 18 min. 9 sec. Range 600 to 3000 km. Cruising speed, with 9550 kg. total weight, 341 km./hr. and range 800 to 3200 km. Long description, characteristics and performance *Les Ailes*, May 18, 1939, page 9, 3 illus., 4 tables.

A New Multi-Gun Fighter. All parts of the new Martin single-seater multi-gun fighter monoplane which is designed for easy production, can, if necessary, be fabricated in small workshops throughout the country and be sent to a central factory for final assembly, according to claims. Twenty machines a week could be turned out by a factory employing 2000 people. With exception of wing covering, machine is entirely of steel construction. Quickly detachable panels are fitted around the fuselage, which is of tubular construction. Main portion of cockpit enclosure hinges back to the starboard side. Oil coolers are fitted in the fixed undercarriage leg on the port side and cooling air for the Napier Dagger 24-cylinder 1000-hp. engine is exhausted through a controlled outlet on the underside of the fuselage.

Airplane was taken to 10,000 ft. and put into what appeared to be a vertical dive with engine off, reaching at least 400 m.p.h. when the A.S.I. needle went "off the clock." Particularly impressive was the tightness of the turns probably due to the comparatively short wing span. An electrically operated "crash post" is normally housed within the cockpit enclosure. Span 34 ft. Fuselage 34 ft. 6 in. *Flight*, June 1, 1939, page 563, 4 illus. Photographs only. *Aeroplane*, May 31, 1939, page 688, 3 illus.

Normalizing the Stall. Some air impressions of the two-seater Tipsy with built-in wing slots are described. Stalled airflow over a louvred wing section of the Lockheed 14 fitted with similar slots is diagrammetrically represented. In the Tipsy no degree of violence in the aileron movement, with stick held right back, could, without rudder, be made to cause even a stalled spiral, let alone a spin. Specifications given. *Flight*, June 1, 1939, pages 565–566, 3 illus., 1 table.

ITALY

Nardi Training Plane. FN-305 one- or two-place monoplane for use in cross-country flying by private pilots, for training at civil flight schools, and for advanced training in pursuit and aerobatic work at military schools. Airplane may be powered by a Fiat A70S radial engine of 200 hp., or an Alfa-Romeo 115-1 185-hp. inline engine.

With the Fiat engine, maximum speed 211 m.p.h., cruising speed 189 m.p.h., and gross weight 1800 lb. With the Alpha engine, maximum speed 202 m.p.h., cruising speed 186 m.p.h., and cruising range 435 miles. Description, characteristics and performance. *Aero Digest*, June, 1939, page 122, 4 illus.

U.S.A.

Consolidated Boat for Felixstowe. American Consolidated Model 28-5 long-range military flying boat recently acquired by the British Air Ministry for experimental purposes will shortly be delivered to Felixstowe. It is believed to have Pratt and Whitney Twin-Wasp engines which should give a maximum speed not far short of 200 m.p.h. Four machine guns are mounted. Description of PBY flying boats used by the U.S. Navy. *Flight*, June 1, 1939, page 572.

Consolidated 25-Ton Model 31 Flying Boat. New Consolidated can carry a maximum of 57 passengers for day operations and crew of five, and has sleeper accommodations for 28 passengers for transoceanic flights. As a military flying boat, Model 31 would augment the U.S. Navy PBY-type patrol bomber and is said to embody extensive advances over the PBY type in speed, range and load capacity. Wing span 110 ft. Maximum wing chord 14 ft. Two Wright 18-cylinder double-row engines rated at 2000 hp. for take-off. Few details of construction and equipment but no performance data. *Aero Digest*, June, 1939, page 85, 4 illus. British comments. *Aeroplane*, May 24, 1939, page 644, 1 illus. Long description. *Aeroplane*, June 7, 1939, pages 732–733, 4 illus. Description. *Aviation*, June, 1939, pages 38–39, 3 illus.

Fairchild Model M-62 Low-Wing Training Monoplane. New military or commercial primary trainer is said to meet the U.S. Army Air Corps design requirements and to incorporate aerodynamic and structural refinements to increase safety. Ranger 6-410B-2A 6-cylinder inverted inline aircooled engine rated at 165 hp. at 2450 r.p.m. Wing span 36 ft. Wing area 200 sq. ft. Useful load 663 lb. Maximum speed 141 m.p.h. Cruising speed at 5000 ft., 75 percent power, 138 m.p.h. Cruising range at 5000 ft. 520 miles. *Aero Digest*, June, 1939, pages 93–94, 6 illus.

The Internal Radiator. H. Rabatel. "Our opinion is that the Curtiss P-37 solution and those of the Lockheed XP-38 and Bell XP-39, utilize a circuit of air too bent and too short, and therefore defective. It is necessary conveniently to lengthen the pipes, to reduce their sharp bends, and consequently to eliminate the turbulences entirely by keeping the radiator immediately behind the engine. . . . If it is possible to fit the radiator closely over the engine itself this would be so much the better because it would gain in compactness. Finally, the evacuation of the hot air would be more advantageous by utilizing the Karman flanging between wing and fuselage which forms a more favorably profiled zone."

Location of radiators on the Curtiss P-37 is compared with that on the Curtiss P-40, and location of radiators on the Bell Airacuda, Lockheed XP-38, and Bell XP-39 are described and criticized, with drawings of these five airplanes indicating location of gills for intake of air and air outlets. Drawings illustrate the Rabatel internal radiator in which the air is taken in behind the engine and the outlets are enclosed by a shield forming armor. Advantages of the radiator located behind the engine are pointed out. *Les Ailes*, June 6, 1939, pages 7–8, 11 illus.

New Clark Plastic Plane with Ranger Engine to Tour Coast. Clark airplane is constructed of a plastic material similar to Bakelite, fuselage being molded in two long sections and subsequently fastened together. Six men are said to have cast ten fuselages in one day. No internal bracing structures are said to be necessary. Wings are constructed of wood and fabric, but corporation is said to be perfecting a method whereby wings may be molded in the same fashion as the fuselage, without the necessity for any internal structure. Wing is highly tapered and is equipped with the Clark slot, said to make the plane perfectly controllable even below stalling speed. Plane is a five-place low-wing monoplane powered with a Ranger 400-hp. engine and has a cruising speed close to 200 m.p.h. Clark does not plan to go into commercial production but may license other manufacturers to use this fabrication process. *Western Flying*, June, 1939, page 28, 1 illus.

Aircraft Accidents

British Official Accident Report. Accident on November 4, 1938, involving an aircraft belonging to Jersey Airways and in which 13 occupants and a man working on the ground were killed, is considered as being due to an error of airmanship on the part of the pilot who, when making a climbing turn in the cloud, inadvertently allowed the aircraft to fall into a sideslip at a height which did not permit recovery of normal control in time to avert disaster. Brief abstract of report. *Aircraft Engineering*, June, 1939, page 232.

A German airplane, which was lost in the fog and flying over French territory, crashed and burned at Villers-sous-Chalamont on May 11. It was one of the newest airplanes of the German Air Force, the Messerschmitt 210 powered by two engines and equipped with four machine guns, photographic apparatus and radio. Speed is near 600 km./hr. Brief reference. *Les Ailes*, May 18, 1939, page 4.

Man Versus Machine. G. C. D. Russell. Opinions expressed in a recent issue on "Safety in the Air" are further discussed. Most flying accidents are caused by too high a landing speed, too long a take-off and the incipient spin. Means to prevent accidents from these causes are discussed, especially the use of slots, with a reference to "flap-gear normally used in the United States, namely, the split flap." *Aeroplane*, May 31, 1939, pages 703–704, 2 illus.

Safety on Margin. Col. Sumpter Smith. Incidents occurring in recent accidents and exemplifying the built-in strength of modern aircraft, and accidents caused by human error are discussed by the chairman of the Air Safety Board, C.A.A. Accidents occurring during landing, failures involving human factors, items to remember in guarding against engine failure, and accidents due to flying close to the ground are considered. Three ways in which industry can be of assistance to the Air Safety Board in cooperating

to prevent recurrence of accidents are suggested. *Western Flying*, June, 1939, pages 12–14, 23, 4 illus.

Air Transportation

Civil Aviation Abroad—Brazil. E. Borda. Development of air traffic in Brazil since 1927; airlines operating in Brazil today and types of aircraft flown in regular service; private flying; aircraft factories; and statistics for 1938. *Aero Digest*, June, 1939, pages 52–53, 5 illus.

1924–1939. Fifteen years of work accomplished by Imperial Airways are traced, and changing ideas in air-transport operation are brought out. Various types of aircraft used during this period are illustrated. A second article describes Imperial Airways' Headquarters.

In a third article entitled "Four Years' Progress," history of British Airways before and since its formation from three individual operating companies is traced. *Flight*, June 15, 1939, pages 606a–606d, 607–611 and 611–612, 27 illus., 1 table.

Air Services in Greece. Major W. T. Blake. Short description of air transport services operating in Greece, and map. *Aeroplane*, June 14, 1939, page 767, 1 illus.

Flight Planning. British Airways' operations department not only carries out all organization necessary in preparing new routes but is also responsible for running all services at the peak of efficiency while retaining a complete record of all flying done by the different airplanes and different pilots. A section is devoted exclusively to airline research problems so that manufacturers can be told exactly what is wanted in the way of equipment and layout of new machines which are ordered. Description of this department and pilot's school. *Flight*, June 15, 1939, pages 613–615, 3 illus.

Airships and Balloons

Airship Mooring in England. Capt. T. B. Williams. Mooring trials carried out in February, 1921, by letting the airship up on her wire about 300 ft. and hauling it down and securing it. Behavior of the ship at the mast, and incidences of bad weather conditions encountered by airships at the mast are described. *Airship*, April–June, 1939, pages 4–5, 3 illus.

Convoying Ships. Need for British nonrigid airships for convoying purposes is considered with examples of their use during the world war. Present advantages of airships in regard to speed, vulnerability of the airship, types required, and importance of training are discussed. Convoy airships of the last war are illustrated. *Airship*, April–June, 1939, pages 1–3, 12.

German Barrage Balloons. According to "Die Wehrenmact," barrage balloons or air minefields are being operated around industrial centers in Germany. Balloons are said to have wires hanging from them and that they can fly so high that it will be impossible for bombers to fly over them. Other sources state that their ceiling is about 8000 ft. German balloons have gas-filled stabilizers, or at least the stabilizers, even if air-filled, always are at a positive pressure. Brief note. *Airship*, April–June, 1939, page 3, 1 illus.

Hot Air Balloons. E. Abel. Hot-air balloon which has so far been very successful has been developed by Marek and Emmer, Vienna balloon builders. Balloon has a globe-shaped fireproof non-rubbered cotton fabric envelope of 77,698-cu. ft. capacity. Burner for production of hot air is built on a tripod situated in the suspension gear under the bottom part of the envelope, latter having a circular opening in its lowest part just above the burner. Burner is petroleum fed forming a very hot thick and short flame which heats the air inside the balloon envelope to a temperature of 330°F. Gasoline is carried in two tanks situated in the car and having a capacity so as to ensure a burning duration of 4 to 5 hr. Weight of balloon plus ropework and car 594 lb. With crew of three men balloon can reach a maximum height of 13,120 ft. Description. *Airship*, April–June, 1939, page 8.

Why Has Not the Airship Made Greater Progress? C. B. Fritsche. For a development program, construction of a Metalclad airship is recommended which would have a gas volume of about 1,500,000 cu.ft., top speed of 150 m.p.h., cruising speed of 120 m.p.h. and which would be equipped with a nacelle keel so designed as to enable the airship to land on any protected harbor with its crew, take on water ballast through submarine valves located in the keel and taxi up to a floating stub mast for mooring purposes. *Airship*, April–June, 1939, pages 9–10, 2 illus.

Gliders

Briegleb Glider for Training and Soaring. BG-6 single-seater trainer and soaring glider may be assembled in ten minutes by two men. Wing span 32 ft. 3 in. Wing area 117 sq.ft. Wing loading 3.2 lb./sq.ft. *Aero Digest*, June, 1939, page 101, 4 illus.

Standard Sailplane for Olympic Games. After analyzing the results of five different types of gliders submitted by Germany, Italy and Poland to evolve a standardized type of sailplane in this competition, the F.A.I. decided to adopt the DFS-Meise designed and constructed by H. Jacobs, chief engineer of the Darmstadt Gliding Institute. For steepening the gliding angle spoilers are provided, a simple system of levers which is illustrated extending the spoilers above and below the wing in which they normally lie completely flush. Wing span 49 ft. 4 in. Wing area 161½ sq.ft. Test flights have given a gliding angle of 1 in 25, a sinking speed of 132 ft./min. and a stalling speed of 31 m.p.h. Brief note. *Flight*, June 8, 1939, page 586f, 2 illus.

Wings on the Wind. M. A. Garbell. Use of thinner wing sections for gliders, lower wing loading, greater comfort and safety for the pilot, and better instrumentation are trends in glider design in Europe. Sailplanes intended for high altitude work must be very strong and have greater stability than normal sailplanes. They must be fitted with electrically heated and electrically operated instruments, with oxygen equipment, and must carry protection against control failure through freezing. Discussion on design trends in Germany and Italy includes: design of the Jacobs Reiher, Weihe and Meise sailplanes which have been very successful in the last international and German meets; problems raised by the extreme conditions of temperature and humidity under which modern sailplanes fly; selection of materials for sailplanes; design of tailless soaring machines to reduce overall drag by eliminating the fuselage; sensitive and safe instruments; popularity of winch towing; airplane tow-offs; intense blind-flying training at most secondary schools; and safety in a landing. *Aviation*, June, 1939, pages 18–23, 76, 30 illus.

Propellers

Development and Production of the New Freedman-Burnham Propeller. G. L. Freedman. By the method developed for completely impregnating only the shank end of the propeller blade to make it impervious to moisture or atmospheric changes every particle and fiber of the shank are filled. Method developed to increase strength of blade shank far beyond that imparted by impregnation consists of one-piece steel cup compressed on and bonded to the plastic impregnated wood shank, cup being applied to shank after impregnation and before polymerization, since shank at this point is in a somewhat plastic stage. Results of tests of the propeller for failure and of tests of the ability of the propeller shanks to resist atmospheric changes and strength of the metal-sleeved shank, statically and dynamically, are described. Processes in constructing blades and hubs, and various types produced are described. Propellers for engines from 40 to 90 hp. are in production and design is under way for models suitable for engines from 100 to 300 hp. *Aero Digest*, June, 1939, pages 73–74, 77–78, 12 illus., equations.

New Variable Pitch Propellers. Constant Speed Airscrews, Ltd., has acquired the license for fabrication of the V.D.M. variable-pitch propeller permitting an axial fire from a cannon and controlled by electric motor. Piaggio has constructed a propeller with automatically variable pitch and feathering, known as the P.1001. Change of pitch is realized by the speed of the motor and electromagnetic control. For jts Me-106 Taifun, equipped with an Argus As-10 240-hp. engine, Messerschmitt has designed a variable-pitch propeller of 2.35-meter diameter weighing 37 kg. and characterized by an extremely simple mechanism which the pilot controls from the instrument board by means of a crank. Motion is transmitted by a gear, a differential screw and a grooved ring. The blades are of wood of the Schwarz type and can rotate 10°, realizing both large and small pitch. Allison has constructed for its new 2600-hp. engine a three-bladed constant-speed propeller of 5.52-meter diameter.

The English have calculated that the use of blades of wood on variable-pitch propellers permits a gain of 50 percent on the weight, which, for a four-engined Short, represents 500 kg. of the useful load, or a gain of 1,800,000 francs per year for the British fleet. Evidently the blades of wood are developed and made in an entirely modern fashion, in fine layers of impregnated wood and protected by an envelope of plastic material.

A part of the energy contained in the propeller slipstream can be recuperated by placing behind the propeller, on the engine nacelle, directing blades which supply a supplementary power to the airplane. Brief references only. *Les Ailes*, May 25, 1939, page 7.

A Note on Some Simple Airscrew Considerations. Idea of the calculations given is to replace the whole of the propeller blades by a "wing" turning round with a speed equal to that of a blade element at 0.75 of the propeller radius. Wing area is quite arbitrary and may be taken equal to the square of the diameter D. Further increase in flying speed would lead to decreased maximum efficiency unless this is counterbalanced by higher circumferential speed. Other considerations, approach to the speed of sound, energy loss through emission of sound waves, make it impossible to maintain the 45° blade angle by increasing the circumferential speed. It is, therefore, shown what would happen for a propeller with infinite pitch and 90° blade angle. *Flight, Aircraft Engr. Sup.*, June 1, 1939, pages 21–22, 2 illus., equations.

A Study of Air Movement Through Axial-Flow Free-Air Propellers. M. F. Dowell. Ultra-high-speed motion-picture camera, rotating pitot tube, stroboscope and rotating microphone described were used in studies of airflow on the axial-flow free-air propeller in the General Electric Company laboratories. Discussion also covers: analogy of flow of air through orifices and through propellers; contrast of two-dimensional wing-foil flow with propeller-foil flow; actuation of air by a foil section; tip-vortex formation; noise considerations in propellers in regard to peripheral velocity, velocity of air and angle of attack; obstructions and recirculation of air; acceleration of air in the blade volume; curvature of elements; and tip-vortex interference. *General Electric Rev.*, May, 1939, pages 210–217, 17 illus.

Aircraft Instruments and Navigation

Aeronautical Charts Prepared by the Coast & Geodetic Survey. Air navigation charts discussed were compiled from basic survey data of the U.S. Coast and Geodetic Survey and from the best topographic data from other sources and flight checked by the Bureau. Charts for instrument flying, and sectional and regional charts are described. *Aero Digest*, June, 1939, pages 61–62, 2 illus.

Averaging Bubble Sextant Observations. Lt.-Comm. P. V. H. Weems. Use of the bubble sextant in both sea and air navigation, accidental bubble-sextant errors, and a graphic analysis of probable bubble acceleration errors based on 110 observations taken in an open-cockpit two-seater airplane. *U.S. Naval Inst., Proc.*, June, 1939, pages 861–864, 2 illus., 2 tables.

Uses of the Librascope in Airline Operations. Capt. H. H. Gallup. Librascope is an automatic computer, specially designed from original equations for each airplane, and is used by Transcontinental and Western Air to predetermine the actual center of gravity of a plane in flight under a given loading condition. Basis of operation of the Librascope, ideal loading conditions, and effect on take-off of correct loading are described, and practical problems which T.W.A. has solved by its use are outlined. *Aero Digest*, June, 1939, pages 56–57, 2 illus., equations.

The Modern Aircraft Compass. F. Chichester. Present types of compasses, and possible developments in the near future. Disadvantages of the existing bowl compass with horizontal face (which is almost the only kind of compass in use in Great Britain) and disadvantages of the aperiodic compass are discussed. Latter suffers from changes in deviation due to varying magnetic disturbance in the vicinity of the pilot's seat, and to the generator. The pilot would like a vertical reading compass which can be set in the instrument panel showing at a glance the course on which the airplane is flying, with no adjustment of grid wires. The early type of magnetic compass, the instrument-panel compass of this type developed and refined by Hughes, and an alternative such as the Kollsman direction indicator are considered. Ideal instrument may be a master compass able to operate three dials at a distance, one for each pilot and one for the navigator. Master instrument can then be placed in the best situation in the plane where the magnetic needle will be less affected by electrical or other disturbance. *Flight*, June 22, 1939, pages 630f–630g, 1 illus.

The Rate-of-Climb Indicator Reads "Dive," the Anemometer Reads "Stall." What Should the Pilot Do? According to the direction of the gusts whicb act on the airplane, the rate-of-climb indicator and the anemometer, basic blind-flying instruments, give contrary indications leading to exactly opposite control, and resulting in serious dangers for an airplane flying near its load limit.

American methods of flying blind by instruments, and especially the Stark system, are criticized. Action of the gyroscope (artificial horizon or automatic pilot), the rate-of-climb indicator, the anemometer, and Constantin wind vanes is considered for the cases of end gusts, rear gusts, and vertical ascending and descending gusts. Indications of the gyroscope are said to be dangerous to follow in the case of rear or ascending gusts. Piloting by the controlled anemometer seems to be the best system. *Les Ailes*, June 8, 1939, page 6.

Electrical Equipment

A.C. for Aircraft? P. C. Sandretto. Present situation regarding power supply for aircraft, and some of the problems for the immediate future. Both the three-phase 400-cycle system at 115 volts and the single-phase 800-cycle system at the same voltage are practical. Advantage of one over the other can be deduced from the equation given. Voltage, direct bearing of the frequency of the a.c. system on the pounds per kilowatt weight of a transformer, and choice of phase as affecting the motors and distribution system, are discussed. Characteristics for motors of both the 400-cycle three-phase system and the 800-cycle single-phase system are given. *Aviation*, June, 1939, pages 30–31, 43, 45, 6 illus.

Liquidometer Offers a New Line of D.C. Electric Pressure Gages. There are three different transmitters, one for fuel pressure, one for oil pressure, and one for manifold pressure, and the electrical resistance assemblies in all these units are similar. Few details. *Aviation*, June, 1939, page 48, 1 illus.

Testing Apparatus

General Principles of Instrument Analysis. C. S. Draper and G. V. Schliestett. Method of attack used at M.I.T. to systematize and simplify the study of instrument problems. Instrument analysis has for its object the calculation of performance to aid in planning the design, to determine the suitability of a certain instrument for a given job, or to correct actual readings for errors from various sources. It is therefore convenient to consider any instrument, however complicated, as made up of one or more elementary instruments each of which is essentially a system with one degree of freedom. Specification of performance, dynamic errors of an elementary instrument, expressions for transient, equation to express the steady-state behavior of an elementary instrument, and the complete response equation are discussed. *Instruments*, May, 1939, pages 137–142, 7 illus., 21 equations, 3 charts.

A Method for Indicating Speeds of Rotation. G. Morris and R. S. Silver. In the method described, frequency of current generated by rotation of a small bar of iron or mild steel, attached to a rotor and in the field of an electro-magnet, is measured by a vibration galvanometer adjusted to reasonance with a multiple of required rate of revolution. *Jour. Scientific Instruments*, May, 1939, pages 149–150, 1 illus.

Metals

Stainless Forging Metals. W. Naujoks. Various ferrous and nonferrous metals and alloys suitable for manufacture into drop forgings which are noncorrosive. Stainless steels as well as copper- and nickel-base alloys are reviewed as to their metallurgical and working properties. Photographs show structure of five types of stainless steel, forged free-turning brass, forged olympic bronze, age-hardening nickel-aluminum bronze, forged Monel metal and forged Inconel. Compositions are shown in a table. *Metals & Alloys*, May, 1939, pages 144–150, 18 illus., 1 table.

The Theory of Metallic Structure. Many of the characteristic properties of polycrystalline metallic masses may be interpreted from the behavior of metal single crystals. Classification of metals according to their lattice structure is discussed and significance of the structure is explained. To be continued. *Light Metals*, June, 1939, page 193, 1 table.

Corrosion and Protective Coatings

Plating on Aluminium. W. J. Travers. In the new process described no effort is made to prevent formation of the ordinary oxide film, but a substantial film of the anodic type is purposely formed on the aluminum surface. Process is based on the principle that an anodically treated surface of aluminum, subsequently subjected to a chemical reduction or modifying reaction, will make the surface susceptible to receiving a very adherent and impervious electrodeposit. Anodic film may be formed on the aluminum surface in a variety of electrolytes, both acid and alkaline, but more uniform results have been obtained by using solutions of certain organic acids, of which oxalic acid may be taken as an example.

Anodic film is thought to be made up of hydrated aluminum oxide together with a gaseous component and to vary with type of electrolyte in which it was formed and also perhaps with the density of electric current employed in its formation and whether direct or alternating. Electrochemical Society paper. *Metal Industry*, June 2, 1939, pages 591–592.

Iron and Steel

The Effect of Nitrogen Additions and Heat-Treatment on the Properties of High-Chromium Steels. E. W. Colbeck and R. P. Garner. Manufacture of high-chromium steels containing varying amounts of nitrogen and the effect of heat treatment upon their properties were investigated. Addition of nitrogen to these steels had a marked effect in refining their naturally coarse grain size. A method is described for introducing nitrogen into steels containing 21 to 28 percent chromium. Best results have been obtained with steels containing between 22.5 and 28 percent of chromium, in which nitrogen content is approximately one hundredth of the chromium content and nickel is present in amounts of ½ to 1½ percent. Communication from the Research Department, Imperial Chemical Industries, Ltd. British Iron and Steel Institute paper. *Engineering*, June 16, 1939, pages 726–729, 8 illus.

Research on Alloy Steels. Brief abstracts of sections included in the Second Report of the Alloy Steels Research Committee, British Iron and Steel Institute and British Iron and Steel Federation, covering: results of study of the delta region of the iron-nickel system; scaling of steels in sulfur-free and sulfur-containing atmospheres; application of the electron-diffraction camera to the study of the initial film formed on steels by oxidation; element titanium and its effect upon properties of steel; further work carried out to check changes in torsional elastic limit with temperature; attempt to determine effect, if any, of high-frequency electric currents upon properties of steel; further study of the A3 point in iron-cobalt and other alloys; second report of the Sub-Committee on Thermal Treatment concerning thermal and physical characteristics of 21 different steels; preliminary account of certain investigations into the scientific basis of corrosion fatigue; recent work on the intermediate transformation in alloy steels; methods employed in determining transformation-velocity/temperature curve in the course of studies of alloy steels. *Engineering*, June 2, 1939, pages 663–664. *Engineer*, June 2, 1939, pages 683–684. Discussion following presentation of report. *Engineering*, May 26, 1939, pages 612–614.

Nonferrous Alloys

The Action of Ammonia on Aluminium. Explanation to clarify the anomalous behavior of aqueous ammonia solutions on aluminum. Brief note. *Light Metals*, June, 1939, page 199.

Age-Hardening Magnesium Alloys. W. F. Chubb. Critical dissertation upon the cadmium-magnesium system. Study of published investigations indicates that finality as to the equilibrium diagram of this system has not yet been reached. Work of Urasow and other research workers, action of the compound $MgCd_3$, and lattice characteristics are discussed. To be continued. *Light Metals*, June, 1939, pages 221–223, 5 illus.

Corrosion and Protection of Magnesium Alloys. Types of corrosion; function of impurities; peculiar problems in the case of magnesium in regard to hydrolytic action and other electrochemical considerations; mechanism of corrosion; structure of surface films; choice of testing methods; and accuracy of results. To be continued. *Light Metals*, June, 1939, pages 218–220, 3 illus., 1 table.

Light Metals in American Aircraft Design. H. W. Perry. Major effects produced on airplane design and construction by the development of high-strength light alloys, as listed by engineers of the Boeing Aircraft Company, the transition from wood to metal, and the metal construction used in the Vultee V-11GB attack bomber, are discussed with a brief reference to use of beryllium. *Light Metals*, May, 1939, pages 171–174, 5 illus.

Magnesium Alloys—Their Importance as Engineering Materials. M. Philipp. Properties of magnesium and its alloys used in Germany, and applications, for which they are suitable are discussed, including: commercially pure magnesium, alloys, and refined magnesium as engineering materials; merits and drawbacks of magnesium-alloy castings, and ductile magnesium alloys such as pressings and forgings; machining; prevention of corrosion and surface treatment; joining of parts by riveted, welded and bolted joints; force fits; and use as bearing materials. Composition of German magnesium alloys, and properties of magnesium sand, chill and die-casting alloys, and of ductile alloys are shown in tables. Abstract from "Engineering Progress, Berlin." *Metal Industry*, May 26, 1939, pages 561–565, 3 tables.

Metal Spraying by Powder Pistol. Theory of metallization by spraying is considered with special reference to the physics of powder metallurgy. Special applications of sprayed aluminum coatings are cited. Theory of bonding is discussed, wire and powder pistols are compared, and methods of supplying the powder from container to pistol are taken up. *Light Metals*, May, 1939, pages 187–189, 6 illus.

Testing of Metals

Portable X-Ray Equipment. H. R. Isenburger. X-ray tube attached to the stand of the portable equipment is shock- and ray-proof, air-insulated and water-cooled. Besides the advantage of line focus the tube has a special electron grid which filters the radiation and at the same time practically doubles the penetrating effect. Result is almost no scattering and possibility of obtaining an exograph through 3 in. of steel in a 1-min. exposure using only two-thirds of the voltage ordinarily required. Brief description. *Industrial and Engineering Chemistry, News Ed.*, June 20, 1939, page 423, 3 illus.

Small Equipment for Mechanical Testing. Hounsfield "D"-type tensometer testing machine is described in which the spring beam may readily be changed to accommodate different maximum loads ranging from 62 lb. to 2 tons. Fine-toothed pinion frictionally connected to the spindle and interchangeable springs beams are improved features. Design of small test pieces, special tools and gauges used in producing miniature test pieces quickly and accurately, and neutralization of errors are discussed. *Light Metals*, June, 1939, pages 194–196, 9 illus.

Fatigue of Metals—Developments in the United States. H. F. Moore. Significance and limitations of the endurance (or fatigue) limit; nomenclature and definitions; fatigue testing machines used in the United States; fatigue test specimens; effect of range of stress during a cycle; effect of combined stresses; and effect of speed of testing and size effect. To be concluded. Paper presented at the 1937 M.I.T. Conference on Fatigue of Metals. *Metals & Alloys*, May, 1939, pages 158–162, 2 illus.

Why Gear Teeth Wear. T. R. Rideout. Pitting is the most common kind of gear-tooth wear, and scoring or galling the most serious kind. To assist in determining cause and identifying effect, defects leading to wear, characteristics of various kinds of wear, and their relative importance are classified, illustrated and discussed, including: normal wear; pitting; corrective or incipient pitting; destructive pitting; abrasion; spalling; scoring and galling; scuffing, wiping, and cutting; and rolling or peening. *American Machinist*, June 14, 1939, pages 425–427, 12 illus.

Welding

An Investigation of Unsymmetrical Loading on Lightweight Steel Studs. H. L. Lyell. Relative strengths in compression of various types of steel studs used in light-weight welded building frames. Inside flange of studs received the largest stress.

Variations of stresses in the flanges of all studs were similar in that stresses in the inside flanges became larger in proportion to stresses in the outside flanges as the load on the joists is increased. Tests and results. *Welding Jour., Welding Res. Sup.*, May, 1939, pages 167–174, 15 illus., 2 tables.

Spot Welding Light Metals in a German Aircraft Works. K. Reichel. Spot-welding tests undertaken by the Arado Aircraft Company. Radiographic examination showed that aluminum and Hydronalium (90–95 percent Al, 5–10 percent Mg) generally yielded good welds. Electron (1.8 Mn, 0.3 Si, rem. Mg) was difficult to weld. Alclad also yielded indifferent welds, perhaps because oxide layer and cladding were not of uniform thickness. Hydronalium had the best welding characteristics and was selected for spot-welded structures. Specimens with one or two spots were tested in single shear. Fatigue tests of riveted and welded spars, of heat-treated spars, and of corroded spars, static compression and torsion tests of cylinders, tests on Alclad, and difficulties in spot welding electron (Am 503) are discussed with results. Abstract from D.V.L. Yearbook of 1938, pages 538–548. *Welding Jour., Welding Res. Sup.*, May, 1939, pages 182–184, 3 illus., 3 tables.

Testing the Physical Properties of Welds. O. H. Henry and G. E. Claussen. Tensile tests of all-weld metal and butt welds; free and guided bend tests; fillet-weld shear tests; shear test on spot and flash welds; torsion, notch-impact, fatigue, hardness and corrosion tests, and tests of completed structures; soundness tests (nick-break and fillet-weld break test, etch specimens, and usability and density tests); physical properties considered adequate for specimens of mild-steel welded joints all weld-metal tensile properties, butt-weld tensile strength, free-bend ductility, guided-bend cracking, fillet- and spot-weld shear strengths, notch impact value, and fatigue strength); properties of alloy steels and nonferrous metals; occurrences which may accompany welding and affect the physical properties of base metal in the heat-affected zone (hardening, softening, intergranular effects, and grain growth of the base metal); filler metal composition, porosity and inclusions; and importance of shape of weld for impact resistance and fatigue strength. *Welding Jour., Weld. Res. Sup.*, May, 1939, pages 288–294, 7 illus., 2 tables.

Plastics

The Processing of Plastics. Types available; selection of a plastic in regard to method of fabrication, color and appearance, heat and exposure, strength, electrical resistance, weight and cost; methods of molding phenolics, ureas, cellulose acetate, acrylic plastics, styrene plastics, ethyl-cellulose plastics, and mold construction; punching; blanking, shearing and shaving of plastics; machining of plastics (drilling, reaming, threading, lathe operations, screw-machine work, milling operations, gear cutting and sawing operations); and grinding, polishing, and buffing. Table shows plastics available, their uses and outstanding characteristics. *American Machinist*, June 28, 1939, pages 483–494, 10 illus., 6 tables.

Testing of Materials

Accoustic and General Methods of Non-Destructive Testing. S. F. Dorey. Acoustic methods of testing are briefly reviewed with comments and optical methods are discussed including: polished surfaces; spectrographic analysis; colorimetry; spark testing; Transmeter for photometric determination of opacity of paint; reflection of light to measure luster of textiles; whiteness of fabrics; fluorescence in ultraviolet light to determine oils and fats in textiles; and microscopes. Short survey of general methods of nondestructive testing refers to hydraulic testing; proof-testing chains, lifting appliances, bridges and building structures; anodic oxidation test for cracks; hardness testing; macroetching and sulphur printing; overload tests on electrical machines and prime movers; durability tests for lubricants, paints and varnishes; Schmueckler milling test for welds, glass testing; determination of modulus of elasticity of timber species; determination of moisture content of timber by electric meters; nondestructive tests applicable to rubber; paper testing; testing porosity of bricks; and specific gravity. *Instn. Electrical Engrs., Jour.*, May, 1939, pages 552–557 and (disc.) pages 580–595, 11 illus.

Industrial Radiography on the Continent of Europe. I. J. E. de Graaf. Requirements for sensitivity which seem to be generally higher in Europe than in America; photographic inspection of welds and castings, and fluoroscopy of light metals; and use of results for acceptance tests. *Instn. Electrical Engrs., Jour.*, May, 1939, pages 545–551, 12 illus. and (disc.) pages 580–595, 11 illus.

Non-Destructive Testing in the U.S.A. H. H. Lester, R. L. Sanford and N. L. Mochel. Radiographic methods and their application in the United States in the foundry and weld shops; industrial radiographic committee reports; use of magnetic and electrical methods of nondestructive testing; and acoustical and general methods employed, including vision, hardness tests, proof tests, tests to determine cracks, testing of files and hand-saw blades, tests on coiled springs and on turbine rotor forgings, drilling tests, spark testing, and etching, pressure, hammering and stethoscope tests, and the testing of porcelain and glass. *Instn. Electrical Engrs., Jour.*, May, 1939, pages 565–579, 8 illus. and (disc.) pages 580–595, 11 illus.

Radiography—An Aspect of Non-Destructive Testing. V. E. Pullin. Examination of metallic structures by X-rays, as first started by the author at Woolwich, and its rapid progress are outlined. Planer radiography, visual X-ray examination, use of radium, X-ray crystal analysis, and complementary methods of nondestructive testing are described in detail. Methods of investigation developed in the Research Department at Woolwich are referred to and equipment illustrated. Results obtained are illustrated in radiographs and in graphs. Drawings illustrate the use of radium for: examinations of 10 shells simultaneously and of rivet fits; for locating the end of a crack near a vital wall; in examination of a turbine casing; and as a means of searching a complicated metal form from every possible angle. *Instn. Electrical Engrs., Jour.*, May, 1939, pages 535–544, 31 illus., 1 table and (disc.) pages 580–595, 11 illus.

A Sensitive Optical Strain Gauge. S. C. Redshaw. Strain gauge is capable of measuring positive and negative strains to about 1.0×10^{-6}, on a gauge length of 3 or 4 in., having a linear calibration over a strain range of at least 500×10^{-6}, but could be modified to operate on other gauge lengths. Motion between a fixed and a movable knife edge will rotate a flexure pivot, light from a target being reflected by means of a mirror mounted on the torque bar of the flexure pivot into a microscope unit set in the cover of the gauge and fitted with a screw micrometer eyepiece. *Jour. Scientific Instruments*, May, 1939, pages 150–155, 3 illus.

Bearings

Bearings That Spread. With the object of minimizing risk of damage through overheated plain bearings, Wellworthy Piston Rings, Ltd., have evolved a new bearing metal which, when subjected to extreme heat, spreads without any signs of disintegration. Metal used for the bearing is prepared from R.R.A.C. 9. Results of a test are given in a brief note. *Flight*, June 1, 1939, page 576.

Wear in Lubrication Problems. L. M. Tichvinsky. Various methods and equipment employed to obtain the wear resistance of various metals, especially those used in the design of bearings, are described and illustrated. Boundary or semifluid friction takes place in bearings of practically all rotating machines when started or brought to a standstill, and lasts a short period of time, usually being accompanied by the wearing of bearing surface, journal surface, or both. Wear takes place also in the case of antifriction bearings due to sliding, rolling, or combined sliding and rolling friction. Many other causes, such as misalignment, dirt, or inadequate lubrication, might be responsible for wearing of any type of bearing. Electron-diffraction method, as peculiarly adapted for the study of surface phenomena, is described in the appendix. *A.S.M.E. Trans.*, May, 1939, pages 335–346, 29 illus.

An Investigation of the Warlop Bush. D. Clayton and M. J. Wilke. Coefficient of friction of the Warlop bush was shown to be greater than that of a plain bush, over the range of conditions of the tests undertaken at the National Physical Laboratory, as part of the program on research on lubrication. Limit to fluid-film lubrication is reached earlier with the Warlop bush as speed is decreased. Behavior is better when there are fewer holes and connecting channels, but it is still inferior. The N.P.L. journal-bearing machine used in the test is described. Warlop bush is a liner to the usual bush, and is pierced radially by a series of holes, which are joined by circumferential and axial or helical channels cut in the outside surface of the liner. It was claimed that holes and channels allowed the lubricant to return through them from regions of higher pressure to regions of lower pressure, thus avoiding return currents within the clearance space itself, allowing film to form more easily on starting and reducing viscous friction during running. *Engineer*, June 23, 1939, pages 761–763, 5 illus., 2 tables.

A New Bearing Metal. New R.R.A.C. 9 bearing metal suitable for every type of motor has been produced by Wellworthy Piston Rings, Ltd., and is said to be superior to both white metal and bronze. Commercial engine was tested with a pair of bearings made from this metal which had less clearance than recommended. This reduced clearance was intentional and made itself obvious in loss of power when running with full load. Loss gradually remedied itself and engine continued to run normally on full load a further 20 hr. On inspection, bearings were found to be comparatively smoother and free from ridges and surface abrasions. One-half showed signs of seizure. Apparently under extreme heat the metal had spread without any signs of disintegration. Toward each end of the half bearing the measurement was 0.040 greater than toward the center, proving that under excessive heat a general spread of material had taken place to give the clearance required for proper working. *Aeroplane*, June 21, 1939, page 809.

A New Needle Bearing. Ransome and Marles needle roller bearings in which the rollers have trunnion instead of spherical ends. Description of design and method of assembly which is said to aid rapid production. *Aircraft Engineering*, June, 1939, page 254, 6 illus. *Aeroplane*, June 14, 1939, page 772, 1 illus.

Fuels and Lubricants

Dopes for Diesel Fuels. By adding 5 percent of ethyl nitrate to gas oil, cetane number was raised from 62 to 80 and a 10 percent addition of the nitrate increased it to more than 95, according to studies of M. Clerget. Action of the antidetonant was improved by addition of benzoyl bromide and of amyl bromide. According to C. Bertholet, if 0.5 percent ethyl nitrate and 0.5 percent benzoyl bromide are added to a medium-volatility distillate of low temperature tar, duration of combustion is reduced by more than two-thirds. Mercury compounds and various organic products such as fulminates and nitrobenzenes are proposed as dopes for Diesel fuels. Very brief abstract *La Technique Moderne*, May 1. *Automotive Industries*, June 1, 1939, pages 686, 691.

Experiments with Doped Fuels for High Speed Diesel Engines. J. J. Broeze and J. O. Hinze, Delft Laboratory, Royal Dutch Shell. Requirements which a dope has to fulfill to improve ignition quality of a fuel, and results obtained with acetone peroxide and ethyl nitrate as dopes. The influence of these dopes on ignition delay of a fuel, on further stages of the combustion process, and on wear (corrosive action) and incrustations in the engine are discussed in detail. Stability during storage and the matter of safety (explosiveness) are also considered. Storage during several years of 100 percent pure ethyl nitrate had not had a measurable influence on its effectiveness as a dope. Acetone peroxide obtained in the pure state in the form of white crystals has an explosive character but when in solution this explosive character is reduced practically to zero. Data given on the effect of acetone peroxide or ethyl nitrate on the flashpoint of the fuel show that acetone peroxide as dope has no important effect on the flashpoint when any trace of acetone is removed by washing the doped fuel with water. Ethyl nitrate causes an appreciable decrease of flashpoint, which, in the case mentioned, has brought the flashpoint under the value tolerated in many specifications. *S.A.E. Preprint for World Automotive Engg. Congress*, May–June, 1939, 24 pages, 14 illus., 6 tables, 8 equations.

New German Motor-Fuel Regulations. German regulations concerning composition and antiknock qualities of motor fuels for carburetor engines. Gasoline-benzol mixture is to have an octane number of 80 (determined by CFR Research Method). Super gasoline must have an octane number of about 80 (maximum 82). Up to 0.4 cu.cm. tetraethyl lead per liter is to be added to the gasoline. Two other grades which must have an octane number of 74 are mentioned also. Brief abstract. *A.T.Z.*, April 25. *Automotive Industries*, July 1, 1939, page 41.

Engine Design and Research

Aircraft Engines and Their Lubrication. A. Nutt, Wright Aeronautical Corporation. Development of aircraft engines is destined to continue at an accelerated rate during the next five years as results of research on details are applied. An increased number of types will appear as more care is taken to design special engine types for the various airplane types. A revival of liquid cooling will be seen, particularly for military work. Progress over the past fourteen years is reviewed as an indication of what has been taking place and what may take place in future.

Cooling, supercharging, dynamic damper, spark plugs, fuels, dynamic suspension, materials, compression-ignition *versus* Otto-cycle spark-ignition engines, fuel injection, coaxial propellers, liquid-cooled *versus* aircooled engines, engine types, sleeve-valve *versus* poppet-valve engines, and lubrication are discussed, and engines built in this country are compared with those built abroad. *S.A.E. Preprint for World Automotive Engg. Congress*, May–June, 1939, 19 pages, 7 illus., 1 table.

Fundamental Mechanical Aspects of Boundary Lubrication. H. Blok, Delft Laboratory, Royal Dutch Shell. Rational classification of various types of boundary lubrication can be drawn up on the basis of mechanical conditions in region of contact between rubbing surfaces. It may be expected that the physico-chemical results may be fitted in well. Nature of contact is considered separately for concentrated and for dispersed contact. Local contact pressures and their distribution in the region of contact are described which, besides being dependent on the load, are chiefly dependent on the geometrical features of the rubbing surfaces and on their elastic and plastic properties. Local temperatures and their distribution in the region of contact are discussed which are dependent on local pressures, on dimensions of surfaces of actual contact, on coefficient of kinetic friction, on movements of rubbing surfaces relative to the surfaces of actual contact, and on thermal properties of the rubbing surfaces. The following effects of motion, with the exception of tangential vibrations, are considered for concentrated and disbursed contacts: oil wedge formation, frictional stresses, temperature flashes and thermal stresses, effects of impact loading, and duty-recovery cycle. Mild, high-temperature, high-pressure, and extreme boundary lubrication are considered in detail. Appendix gives a survey of experimental data on frictional vibrations under conditions of boundary lubrications, importance and occurrence of frictional vibrations, and theory of frictional relaxation vibrations. *S.A.E. Preprint for World Automotive Engg. Congress*, May–June, 1939, 34 pages, 10 illus., 17 equations.

Methods of Rotor-Unbalance Determination. J. G. Baker. Conventional method of calculating unbalance corrections from vibration readings is reviewed, and its limitations and errors are pointed out. An extension of the method is developed which is simpler and more accurate. Mathematical method is developed for determining unbalance corrections in cases where locations of the corrections are completely prescribed in contradistinction to the ordinary case in which axial position of the correction is prescribed but angular position is to be determined. Balancing machine described reads directly the unbalance corrections required at four preselected locations in a rigid rotor, and is especially suited for quick determination of unbalance corrections required in an internal-combustion-engine crankshaft. Center-of-percussion balancing is described which is a method of taking vibration readings which can be interpreted directly in terms of unbalance. This method is applicable only under conditions noted. *Jour. Applied Mechanics*, March, 1939, pages A-1–A-6, 7 illus., 54 equations.

Piston-Ring Blow-By on High-Speed Petrol Engines. C. G. Williams and H. A. Young. Conditions under which excessive blow-by occurs, and the influence thereon of certain features of piston-ring design. First issue—tests on a single-cylinder O.H.V. water-cooled engine; effects of side clearance and of radial pressure; part played by individual rings in encouraging or resisting blow-by and ring flutter; effects of rate of oil flow upon ring flutter and blow-by; and composition of blow-by gases.

Second issue—tests on a single-cylinder O.H.V. air-cooled engine, and results in regard to: effects of running-in, brake m.e.p., ring side clearance, piston-ring width, ring gap, clearance behind rings, radial pressure, bevelled rings, number of rings, oil viscosity, and spark advance; and composition of blow-by gases. Preliminary results of tests on a multicylinder engine are also considered. Several theories on the origin of ring flutter are outlined.

Narrow piston rings, high-pressure rings, and reduced side clearance were shown to be beneficial insofar as blow-by control is concerned. Narrow rings of relatively low pressure are more effective than rings of high radial pressure and they are easier to fit without breaking or overstraining than are high-pressure rings. On a high-speed engine, improved results are obtained by use of a single pressure ring. First Interim Report to the Research Committee, Institution of Automobile Engineers. *Engineering*, June 9 and 16, 1939, pages 693–694 and 723–726, 20 illus., 2 tables.

Some Applications of Normal Coordinates to Engineering Vibration Systems. R. Eksergian. Torsional systems are analyzed in regard to their free and forced vibrations, and stresses are calculated with the application of normal coordinates and effect of damping which introduces couplings between the modes. Cases considered include: a two-mass torsion system with elastic coupling; a single reduction-geared system; a flexible geared system; and systems with damping. *Franklin Inst., Jour.*, May, 1939, pages 673–690, 3 illus., 57 equations.

Some European Comments on High-Output Automobile and Aero Engines. W. P. Ricart and Sandro Sirtori, Soc. An. Alfa Romeo-Milano. With gasolines of technical isooctane type, cylinder measurements decidedly smaller than the normal ones used today in aero-engine practice are the most efficient for the best power-weight ratio. For high-power units the whole architecture of aero engines should be revised if the maximum in output and the lightest weight possible are to be obtained. The authors favor cylinders with bores not larger than 5-in. and no more than 120-cu.in. swept volume for developments of future highly boosted aero engines. Racing-engine development, preference for smaller aero-engine cylinders, and special European requirements in motor-car engines are considered. *S.A.E. Preprint for World Automotive Engg. Congress*, May–June, 1939, 12 pages, 7 illus.

Technical Notes. Jean Guichard has described what is an interesting use of the thermal energy of the exhaust gases, first as deicers, and second for adding to the lift of a wing. A tube can be placed in the interior of the leading edge of the wing, and the exhaust gases directed through it. As these gases flow at a speed higher than the flow of fillets of air over the wing, they can be led out by manifolds conveniently placed on the upper surface of the profile, which increases the lift by realizing the effect of blowing, and that without any mechanical control. This arrangement avoids also the zone of dead air which exists behind the trailing edge and where all the aerodynamic phenomena begin which act on the wing. This release of kinetic energy should retard the breaking away of the flow and improve the qualities of the wing. Brief note. *Les Ailes*, May 18, 1939, page 7.

Exhaust gases of engines produce an electrostatic charge in the exhaust pipes which is communicated to the whole airplane and leads to radio disturbances. This effect is greater with heavy-oil engines and increases with speed and altitude. This phenomenon was mentioned at the recent Lilienthal Congress. It is suggested that a relation could be established between this electrostatic charge and formation of ice on the airplane, since the mechanism of icing also increases with speed of airplanes.

A paper presented at the German Academy of Aeronautical Research tended to show that above 500 km./hr. it is useless to use a turbine for recuperating the energy of the exhaust gases, since direct utilization of these gases in reaction nozzles supplies, in a very simple and direct fashion, a propulsive force which gains a fifth of this energy. Also if one estimates briefly that the power lost in the exhaust is equal to that furnished to the crankshaft, and equal also to that dissipated in the radiator, one sees that on an engine of 1000 hp. the exhaust nozzles permit the recuperation of 200 hp. almost gratis. Brief references. *Les Ailes*, May 25, 1939, page 7.

Bore Wear from the Viewpoint of Materials. P. Lane. Cylinder and ring wear are considered mainly from the standpoint of the materials used and various data accumulated over several years through laboratory wear testing are illustrated. Wear-testing apparatus, automotive engines and bore structures, piston-ring structures, piston-ring wear; piston-ring antiscuff qualities; types of gray iron structures; aircraft-engine tests; hardness and wear balance; sleeve and liner materials; and hardness-structure-wear. *S.A.E. Preprint for World Automotive Engg. Congress*, May–June, 1939, 14 pages, 2 illus., 6 tables.

Engine Bearings—from Design to Maintenance. A. B. Willi, Federal-Mogul Corporation. Faulty design or too much engineering compromise both in the bearings themselves or in associated parts of the engine are pointed out as major causes of bearing failures. Other causes of bearing failure; materials used in bearing construction; effect of temperature on the physical properties of white metals; the bearing back; oil flow to connecting-rod bearings; oil-feed-groove restrictions; oil clearance; elements of bearing manufacture which affect performance and life; length of tubes for centrifugally cast bearings; preparation of steel tube for babbitting; finishing the bearing back; more comprehensive specifications which are required; bearing failures caused by faulty installation and misuse and abuse in operation; and those caused by the use of inferior lubricants or good lubricants improperly prescribed and used; and rate of bearing deterioration. *S.A.E. Preprint for World Automotive Engg. Congress*, May–June, 1939, 20 pages, 10 illus.

Engine Flame Researches. T. A. Boyd, Research Laboratories Division, General Motors Corp. Tabloid review of a long research on engine combustion. Investigation has been concerned in large measure with the knock, but knowledge of knock-free combustion has been sought as well. Midgley optical gas-engine indicator, bouncing-pin indicator, auxiliary sampling valve, and observations through windows are described. A study of radiation characteristics, spectroscopic studies, flame temperature measurements, full-view pictures of engine flames, and utilization of flame studies are considered. Since a definite relationship has been established between volume inflamed and mass burned, and between mass burned and pressure developed, when piston motion has been taken into account, essential relationships which have been established in this research can be derived directly from accurate pressure cards without using the flame pictures. Results of the researches have shown how valuable a precise pressure indicator can be in the study of combustion events, and how to use it for finding such factors as volume inflamed and mass burned at any instant. *S.A.E. Preprint for World Automotive Engg. Congress*, May–June, 1939, 25 pages, 30 illus.

The Influence of Speed on Heat Loss in Petrol Engines. W. T. David. An attempt is made to investigate the influence of speed upon distribution of heat loss from the hot gases in a gasoline engine to the cylinder head and barrel, and to the exhaust valves or ports and passages beyond. Results of an analysis of a gasoline engine (4.5-in. bore, compression ratio 5) are of considerable practical significance in that they show that the burden of transmitting to the cooling water the increased heat loss with increase of speed is thrown entirely upon the exhaust system. Heat loss to the cylinder head increased by about 20 percent, with an increase of speed of about 60 percent. Amount by which the total heat to the cooling water increases with speed will depend upon the length and design of the exhaust passages, and upon the amount of surface in the path of issuing gases. In the case of the sleeve-valve engine with short exhaust passage an increase of speed of 100 percent (that is, from 2000 to 4000 r.p.m.) would probably result in an increase of heat to the cooling water of about 50 percent, whereas the increase might be as much as 75 percent in a poppet-valve engine with a very long and complicated length of exhaust passage. *Engineer*, June 23, 1939, page 765, 4 tables.

Physics of Flames and Explosions of Gases. B. Lewis and G. von Elbe. Self-ignition; ignition by local sources; flame propagation, including flame front, spherical flames, stationary flames, influence of vessel shape and gas motion, detonation, and diffusion flames; state of the burned gas; and incomplete rotational excitation in diatomic gases at ordinary temperatures and pressure. Theoretical calculations and results of tests are discussed and illustrated. *Jour. Applied Physics*, June, 1939, pages 344–359, 19 illus., 16 equations.

Processes in Injection Systems of Oil Engines. S. F. Davies and E. Giffen, King's College, London. General conditions affecting injection systems, analytical treatment of simple systems, experimental results with open nozzles, general conditions regarding spring-loaded nozzle valves, general mathematical treatment of fuel injection systems, and experimental work on systems with spring-loaded nozzle valves are discussed.

Concerning the injection systems of the common type consisting of pump, delivery valve, pipe, and spring-loaded nozzle valve: order of residual pressure prevailing in the pipe between injections relatively to the nozzle-valve opening pressure is of vital importance; opening and closing pressures are generally in proportion to effective area of the open nozzle valve and area exposed to oil pressure when valve is closed; action of volumes of oil in the pump and at the nozzle, in addition to that in the pipe, is to modify considerably the pressure diagram calculated from simple reflections in the piping; injection lag may consist of three periods (passage of disturbance along the pipe, building up of pressure at the nozzle, and opening of the valve); leakage from the system causes a fall of residual pressure between injections thus affecting nozzle lag; increase of pump speed increases injection angle, increases maximum nozzle pressures, modifies total injection lag, increases valve lift and gives a sharper cut-off; rough running caused by alternating injection characteristics is common, and pump and injection setting for normal running should avoid such instability. *S.A.E. Preprint for World Automotive Engg. Congress*, May–June, 1939, 35 pages, 25 illus.

Stacks and Rings. G. F. Titterton. Use of the exhaust for preheating the carburetor air. Types of exhaust collectors are described, including the shroud, intensifier and hot-spot types, and cabin heating and connections for exhaust-driven superchargers are considered. Check measurements of back pressure in each cylinder to check the efficiency of each new design of exhaust collected is recommended, and methods of making back-pressure measurements, the carbon monoxide determination, and temperature measurements are outlined. Recommendations are made for protecting the important parts of the engine installation from excessive exhaust heat caused by increase of power, including intake-manifold and fuel-system design. Concluded. *Aviation*, June, 1939, pages 32–33, 86, 88, 6 illus.

Studies in Lubrication. M. Muskat and F. Morgan. Successive approximation theory for the thick-film lubrication of flooded journal bearings and bearings with circumferential grooves is developed through the fourth approximation, that is, including the fifth power of the journal eccentricity. Analysis applies to bearings of arbitrary length, boundary conditions at the ends of the bearings being satisfied rigorously. Journal eccentricities and friction coefficients, for fixed Sommerfeld variable, were found to be greater for bearings of finite length than for those of infinite length, the difference increasing with decreasing bearing length. Load-carrying capacities, for fixed eccentricity, of the bearings of finite length are much less than that for infinitely long bearing.

General theory for the bearing with a central circumferential groove is also developed and it is shown that the only hydrodynamic effect of such a groove is to cut the bearing into two separate end-fed bearings, each of half original bearing length. Load-carrying and friction properties of these end-fed bearings are identical with those of flooded bearings of same length. Main advantages of such grooving must lie in maintenance of lubricant viscosity by cooling effect of lubricant flow and in overcoming negative pressures and possible film rupture that would develop in a flooded bearing without internal lubricant sources. *Jour. Applied Physics*, June, 1939, pages 398–407, 5 illus., 28 equations.

Engine, Fuel and Lubricant Testing

Effect of Engine Metals on the Deterioration of Motor Oil. B. F. Downing, G. E. Holbrook and J. H. Fuller. Lacquering technique is a valuable aid in segregating the catalytic effect of metals in engine tests on the deterioration of crankcase oil. Total catalytic effect of crankcase iron is much greater than that of CuPb, AgCd, and babbit when the latter are present as connecting rod bearings. Results of the series of tests using phosphorus additive in the oil indicate same conclusion with respect to the predominating effect of iron. Approximately two-thirds of the oil oxidation and deterioration in a clean or new engine is due to catalysis by engine metals.

Principal function of the additive is to protect the oil against harmful effects of the metals. Solution of metals in contact with the lubricant is retarded and metal catalytic effects on oil oxidation are inhibited. Protection extends to rubbing surfaces so that injurious effects of metals are continuously suppressed throughout the useful life of the oil. Reduction in bearing wear or corrosion is indicated as a corollary of the surface protective property of the phosphorus additive and this is confirmed by the bearing wear data given in a table. Tests on a six-cylinder engine were carried out in the form of two series of four runs each on a 1936 Chevrolet connected to a General Electric dynamometer. *Oil & Gas. Jour.*, June, 1939, pages 70, 72, 75, 9 tables.

Pulsating Air Velocity Measurement. N. P. Bailey. Analysis of the weaknesses of three methods of air-velocity measurement, the hot-wire anemometer, Thomas or Callandar meter, and nozzles, orifices, or pitot tubes used with liquid manometers. These methods give unreliable results when airflow is pulsating. Influence of plenum chambers is analyzed. Modified proportional flowmeter is described in which pressure change of a nozzle, orifice or pitot tube produces an air velocity through a small orifice which is always proportional to instantaneous velocity of the main airflow. By

volumetric measurement of the air that passes through the small orifice, average velocity of the main airflow can be determined. Test results obtained with this meter on a $3^1/_4 \times 4^1/_2$-in single-cylinder C.F.R. internal-combustion engine are reported. *A.S.M.E. Trans.*, May, 1939, pages 301–308, 9 illus., 5 tables, 31 equations.

The Effect of Pulsations on Orifice Meters. S. R. Beitler. Three test setups made for investigating effects of pulsation on orifice flowmeters for measurement of gases. Arrangements are described for subjecting meters to pulsation from either the inlet or outlet side and determining the error in measurement. *A.S.M.E. Trans.*, May, 1939, pages 309–314, 5 illus.

Thin Oil Films. W. Claypoole. Method is described for depositing very thin lubricating-oil films of any specified thickness of the order of 10^{-7} in. on polished metal in connection with experiments on boundary friction. Oil to be deposited is converted into a highly dispersed fog consisting largely of positively charged particles. Oil is readily deposited on a negatively charged metal surface at a rate depending on nature of the oil, potential gradient at the metal surface, and concentration of oil particles in the fog. Rate of deposition is best determined by observation of the progressive change in the interference color produced over a thickness range between 5×10^{-6} cm. and 30×10^{-6} cm. Comparison of color with a standard stepped film of barium stearate laid down by the Langmuir and Blodgett technique gives a high degree of accuracy to the determination of film thickness. Experiments have been made on wearability of very thin oil films, and on determination of the coefficient of static friction. An instrument is described which has been found especially suitable for this work. A low value of the coefficient of static friction is a measure of the oiliness value of an oil-metal combination. *A.S.M.E. Trans.*, May, 1939, pages 323–333, 9 illus., 5 tables.

Engine Manufacture

The Manufacture of Hollow Valves. A. Balleret. Taking American valve-production methods as a basis, Hispano Suiza, one of the first European constructors to show interest in hollow valves for aircraft engines, carried out a series of research experiments and developed a forging technique of their own. General principles of this technique are described including: valve steel; special plant required for forging valves; stelliting operations; hardening valve stems; internal cooling of the valves; and finishing valves. Translated by permission of Revue Technique Hispano Suiza, October, 1938. *Aircraft Engineering*, June, 1939, pages 240–242, 13 illus.

Engines

Bristol Sleeve Valve Engines. Bristol single- and double-row air-cooled radial sleeve valve engines ranging from 600 to 1380 maximum hp. are described. Clean design, internal construction, positive valve timing, and accessories mountings are pointed out. The Perseus and Hercules are illustrated but no reference is made to any particular type in the description. *Aero Digest*, June, 1939, pages 102, 134, 3 illus.

Bristol Taurus Motors for Australia. About 250 Bristol Taurus 1065-hp. aircraft engines are to be shipped to Australia to be put into Australian-built Bristol Beaufort bombers, production of which should be in full swing in 1941 in Australia. Eighty Australian technicians will train at the British factory and 20 Bristol engineers will go to Australia with the motors. *Aeroplane*, June 21, 1939, page 782.

Monsoon 100-Hp. Engine. Monsoon 4-cylinder inline inverted air-cooled aircraft engine is an Americanized version of a French Regnier engine offered by the Allied Aviation Corporation. It is rated at 100 hp. at 2285 r.p.m. at sea level. Hobson carburetor is fitted. With a dry weight of but 205 lb., the Monsoon is said to be the lightest engine in the world in its power class. Bore 4 in. Stroke 4.48 in. Compression ratio 6.25 to 1. Fuel and oil consumption 0.42 lb./hp.hr. and 0.004 lb./hp.hr., respectively, at rated power. Width 12.36 in. Height 27 in. Description. *Aviation*, June, 1939, page 36, 2 illus., 1 table.

Lycoming Model 0-145-B 65 H.P. Engine. Horizontally opposed 4-cylinder air-cooled engine of 144.5 cu. in. displacement achieves its increase in power over the Model 0-145-A series by increase in compression ratio and r.p.m. and change in valve timing. Compression ratio 6.5:1. Maximum rating 65 hp. at 2550 r.p.m. Cruising rating 47 hp. at 2300 r.p.m. Bore 3.625 in. Stroke 3.5 in. Weight 155 lb. Fuel consumption $5^1/_2$ gal/hr. at full throttle and $3^3/_4$ gal./hr. at cruising. Description, specifications and performance curves. *Aero Digest*, June, 1939, page 86, 2 illus.

Technical Notes. Two-cycle 18-cylinder double-row radial Diesel aircraft engine of 2000 hp. developed by E. T. Rogers in the United States. Admission of scavenging air furnished by a centrifugal blower driven by the crankshaft, is made by ports which the piston opens at the head of the stroke. Eight exhaust ports are arranged in the head and controlled by a liner of special steel and cooled by sodium as a valve. Bore 165 mm. Stroke 190 mm. Cylinder capacity 74 liters. Compression ratio 15 to 1. Reduction gear 2 to 1. It is hoped that 2000 hp. at 1600 r.p.m. will be obtained and 2250 hp. at 1750 r.p.m. will be available by supercharging for take-off. Pre-injection of 20 percent of the total charge is effected 60° before dead center and 80 percent remaining at 20° before. Short description. *Les Ailes*, May 18, 1939, page 7.

Engine Accessories

British Plugs for U.S. Machines. British K.L.G. R.A.-954 spark plug has completed its Air Ministry laboratory and flight tests while Pratt and Whitney and Lycoming have, as a result of specific tests, carried out by them, granted their approval. Its unscreened counterpart is the 954-RL. These two types and the RV-16/5 are illustrated, former being described briefly. *Flight*, June 1, 1939, page 576, 1 illus.

A Cooling Development. New system to improve the dissipation of heat from annular leading-edge exhaust manifolds of radial motors has been developed by the Bristol Aeroplane Company and is in production for the Perseus engines of the new modified Empire Cabot-class flying boats. Some of the cooling air is bypassed to flow around the standard Bristol forward exhaust manifold, and rest of the cooling air passes over the cylinder. Reversed flow, forward under the inner side of the exhaust manifold and back over the top, is gained by use of a ring-shaped shield or shroud fitted around the nose and inner surface of the exhaust manifold with a passage between. Annular aperture for the outlet between shroud and manifold is near the leading edge of the cowling system where there is an area of relatively low pressure helping to draw air through the system. Inlet is at the back of the shroud under the inner side of the exhaust manifold in the high-pressure region immediately in front of the cylinders, constant flow being maintained through the channel between shroud and exhaust manifold. Cool air is drawn from inside the cowling in front of the cylinders and travels around the exhaust manifold until it joins the main stream over the cowling. Short description. *Aeroplane*, June 14, 1939, page 764, 4 illus.

Formed to Market Aircraft Engine Exhaust Silencers. Davis exhaust silencer, torpedo shaped and formed from Inconel, provides an enclosed expansion chamber for exhaust gases and then mixes them with cold air from the slipstream by means of a venturi throat which forces air through the center of the silencer. At the rear of the silencer gases pass out through a steel mesh cone which further eliminates heat and noise. Even at night no flames are visible from the exhaust end of the silencer. Few details. *Aviation*, June, 1939, page 48, 1 illus.

Steam Power Plants

Steam Power in the Air. It seems possible even now to build a steam power unit of 2000 hp. which would weigh only 3 lb./hp. If the same amount of attention and money were applied to developing a steam drive for aircraft as has been given to the internal combustion engine since 1918, something very useful would no doubt come of it. Limiting power that can be absorbed at one propeller shaft is a factor of difficulty. But if one boiler might supply directly the units driving more than one shaft or if one unit might drive two contrary rotating propellers, as in the famous Fiat design, then a great improvement in power weight would be obtained. Possibilities have been well figured out on paper and it must now await the test of practical experiment. It is no surprise to find that in different quarters aircraft engineers are giving their attention to the steam turbine. System described by Muenzinger in *V.D.I.*, August 20, 1938, is described briefly. System comprises a closed steam circuit with forced-flow boilers and with condensers incorporated in the wings. Editorial. *Engineer*, June 9, 1939, pages 711–712.

Meteorology

Progress in Applying New Synoptic Aids to Day-to-Day Forecasting. R. H. Weightman. Development in the science of weather forecasting, and use of new scientific aids in the Weather Bureau at Washington. Instead of wind velocity being entered in miles per hour, it is now indicated by barbs on the wind-direction arrow. Barometric tendencies are entered on the weather map as well as on the pressure-change map. Considerable time and effort have been devoted to finding some generalized method whereby forecasters could obtain at least some of the benefits of a more complete analysis and these methods are described. *Am. Meteorological Soc., Bul.*, April, 1939, pages 169–177, 6 illus.

Sensitive Open-Scale Instruments for the Detection of Minor Disturbances of the Atmosphere. S. P. Ferguson. Barographs, thermo-hygrograph, anemograph, and nephoscope, specially developed for use during the eclipse of August 31, 1932, and installed for continuous service at several observatories, are described with drawings of the designs. Experiences in operation are discussed. *Am. Meteorological Soc., Bul.*, April, 1939, pages 135–141, 3 illus.

The Artificial Dissipation of Fog. D. Brunt. Of the various chemical and heating methods considered that of heating the fog until all the water drops evaporate appears a more feasible proposition. To evaporate liquid water in a 100-meter cube of fog at 5°C. a total of 48 therms (12×10^8 calories of heat) would have to be applied for dissipation. In order that a space 100 meters wide may be cleared in a fog 100 meters deep, drifting at the rate of 1 meter/sec., about 36 therms/min. must be applied along a line 100 meters long, set at right angles to direction of drift. Estimated rate of heat supply is proportional to depth of fog, its rate of drift, and increase of temperature from ground to top of fog. Heat required could be obtained by burning 7500 cu. ft. of domestic gas or 20 gal./min. of paraffin, the latter being preferred. Burners arranged at uniform distances of 3 to 4 meters apart suggested.

No solution of the problem of clearing a fog in calm conditions has yet been offered. Formation of fog, physical conditions in fog, methods suggested for dissipating fogs, particularly chemical and heating methods, are discussed in detail. Calcium chloride sprays will absorb moisture but spraying would have to be at or near the upper levels which rules them out. *Jour. Scientific Instruments*, May, 1939, pages 137–140. *Aeroplane*, May 31, 1939, page 688.

Aircraft Radio

Precipitation-Static Interference on Aircraft and at Ground Stations. H. M. Hucke. Effect of precipitation static on aircraft reception, and results of an expedition assembled by United Airlines for a study of the subject are described. Meteorological conditions producing static areas were explored by flights through them, and flight tests of all known types of anti-static antennas were made in bad-weather areas and their effectiveness compared. Theory that interference results from corona produced on the plane structure was developed and tested by mounting the plane on insulators and charging it to 100,000 volts with all radio equipment and personnel on board. Method for reducing corona was developed as a result and proved by flight tests. Study of electromagnetic radiation from corona discharges was made with a synthetic static generator, and the operation of metallically shielded antistatic loop antennas was explained and its limitations established. Advantages and limitations of the commercial form of plane discharge system developed are described. Application of aircraft results to ground radio reception is discussed. *Inst. Radio Engrs., Proc.*, May, 1939, pages 301–316, 18 illus.

Ultra-High Frequencies for Federal Airways. H. W. Roberts. Present radio network of communications, advantages of ultra-high frequencies, first steps in the introduction of equipment for the latter, and future steps are discussed. Mobile radio range unit recently delivered to the C.A.A. by Washington Institute of Technology for tests is illustrated and selections of sites for u.h.f. radio ranges on the New York–Chicago airway are described. *Aero Digest*, June, 1939, pages 68–70, 78, 3 illus.

Pilots

Poisoning of Pilots by Carbon Monoxide. R. Sirretta. Taking, for example, an Hispano-Suiza 12Vcrs 860-hp. engine, the author shows that a content of 1.5 percent of carbon monoxide is given off in the exhaust gases at full throttle and more than 15 percent at cruising. At 500 hp. the quantity of carbon monoxide would be of the order of 10 liters/sec. Some indications of the toxicity of carbon monoxide given by Kohn-Abresi are quoted. Assuming a cockpit having a volume of free air of 500 liters, very large for a single-seater pursuit, and exhaust gas of 2 percent carbon monoxide, only 0.5 liter of this gas would cause rapid poisoning of the pilot, with an atmosphere of 1/1000 of carbon monoxide. This small quantity can be sufficient to bring on a loss of control of the airplane and a fatal accident. *Les Ailes*, June 6, 1939, page 8.